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EFFECT OF CALCIUM SULPHATE ON THE SOLUBILITY OF SOILS

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Additional information on the rate of formation of soluble salts in soils as affected by different factors is desirable. One phase of the subject of special interest is the immediate and residuary effects of fertilizing materials on soils. It seems that aside from its theoretical interest, such information should be of assistance in accounting for results that are obtained from the use of certain substances under field conditions. We have interviewed several of the earlier settlers in southern Michigan and have been informed by them that calcium sulphate was used rather freely by some farmers during the earlier stages of the State's agricultural development. The general impression of those whom we interviewed is that the application of calcium sulphate resulted favorably for a time, increasing the yields of small grains and clover, but later on failed to bring the desired results; hence this substance came to be looked upon as a soil stimulant. Some farmers are using it on wheat and clover, although the amount so consumed is relatively small. According to early reports, which are to be considered in a later publication, similar conditions existed in the agricultural regions of some of the eastern States.

Because of the experiences of the early agriculturists, the increasing interest in the fertilizing value of calcium sulphate, and the widespread use of acid phosphate, which contains appreciable amounts of the sulphate, it was considered advisable to investigate the effect of the sulphate both alone and in junction with calcium phosphate on the formation of soluble salts in soils, as well as the effect on the carbon-dioxid production. The freezing-point method was used to determine the former, and the titration method the latter.

METHOD OF PROCEDURE

In determining the effect of the chemicals on the rate of formation of soluble salts, 200 gm. of the soils in question were brought into contact

with 500 cc. each of distilled water and the substance in solution, and allowed to stand 24 hours with several thorough agitations. At the close of this period the mass was transferred to filter paper in large funnels. In some cases the soluble salts were reduced to a very low concentration by washing with distilled water, while in others the soils were removed, after drainage had ceased, but otherwise treated in the same way as in the former instances. The rate of formation of soluble substances in treated and untreated soils was determined under two sets of moisture conditions. The one which is here called low water content approximated the so-called optimum condition for plant growth; and the other, which is here called high water content, was secured by allowing 1 part of soil to 0.7 part of water and provided sufficient moisture to saturate the soil and leave a small column of about ⅛ inch above it.

Soils of the following description were used in all the experiments:

Soil 1, a silt loam, light phase, containing a large amount of organic matter.
Soil 2, a heavy sand, rather low in organic content.
Soil 3, a fine sandy loam with a medium supply of organic matter.
Soil 4, a very fine sand containing a small amount of organic material.
Soil 5, a very heavy silt loam with a very high content of organic matter.
Soil 6, a silt loam well supplied with organic material.

EXPERIMENTAL RESULTS

The first series of experiments to be reported is the one in which the soils were treated with calcium sulphate, drained, and made up to the high water content, or 1 part of soil to 0.7 part distilled water. Treated and untreated portions of each of the soils studied were placed in jelly glasses, which were tightly covered and let stand in the laboratory. At about 4-day intervals they were thoroughly aerated by stirring, the covers being removed for one-half hour or more. The soils employed were air-dry and had been stored in the laboratory about 160 days. The results are set forth in Table I.

TABLE I.—*Effect of calcium sulphate on the solubility of unwashed soils held at high water content for various periods*

Soil No.	Condition of soil.	Freezing-point depressions.					
		After 2 days.	After 4 days.	After 6 days.	After 8 days.	After 10 days.	After 30 days.
		°C.	°C.	°C.	°C.	°C.	°C.
1	Treated	0.042	0.040	0.055	0.058	0.063	0.091
	Untreated	.003	.005	.008	.011	.013	.024
2	Treated	.044	.045	.050	.055	.059	.080
	Untreated	.000	.004	.005	.007	.009	.011
3	Treated	.043	.051	.054	.057	.058	.057
	Untreated	.002	.004	.006	.007	.008	.014
4	Treated	.045	.050	.050	.053	.055	.138
	Untreated	.000	.002	.004	.006	.010	.017
5	Treated	.046	.048	.051	.055	.058	.075
	Untreated	.003	.002	.004	.006	.012	.018
6	Treated	.045	.042	.050	.051	.052	.089
	Untreated	.008	.012	.012	.018	.024	.032

The effect of the calcium sulphate on the rate of formation of soluble salts in the soils investigated is appreciable. According to the data set forth in Table I, as well as other data not recorded, the reaction is rather gradual and prolonged. Of course the initial concentration of the solutions of the treated soils was high, and it is possible that this influenced the rate of changes which afterwards took place in the mass.

It was considered advisable to wash the soils until the concentration of the solution in the soils was at a very low point. This was done, and the series of tests with washed soils was carried on at the same time and under the same conditions as the previous one. The results obtained are presented in Table II. An examination of this table shows that the residuary effect of the calcium sulphate on the rate of formation of soluble substances in the soils is remarkable. The changes in the concentration of the soil solution did not all take place at once but continued for a number of days.

TABLE II.—*Effect of calcium sulphate on the solubility of washed soils held at high water content for various periods*

Soil No.	Condition of soil.	Freezing-point depressions.					
		After 2 days.	After 4 days.	After 6 days.	After 8 days.	After 10 days.	After 30 days.
		°C.	°C.	°C.	°C.	°C.	°C.
1	Treated	0.011	0.015	0.030	0.044	0.071	0.101
	Untreated	.003	.005	.008	.011	.013	.026
2	Treated	.002	.005	.012	.024	.057	.073
	Untreated	.000	.004	.005	.007	.009	.011
3	Treated	.000	.004	.010	.016	.028	.066
	Untreated	.002	.004	.006	.007	.009	.014
4	Treated	.000	.005	.018	.022	.058	.184
	Untreated	.000	.002	.004	.006	.010	.017
5	Treated	.001	.015	.028	.042	.052	.070
	Untreated	.003	.002	.004	.006	.012	.018
6	Treated	.000	.008	.013	.014	.024	.098
	Untreated	.008	.012	.012	.018	.024	.032

A clay loam soil was treated with the calcium-sulphate solution, washed, and let stand 30 days at the high water content, again washed until the freezing-point lowering of the solution in the soil was 0.005° C., and again let stand 30 days. At the end of this period the freezing-point lowering of the control or untreated soil was 0.040°, and that of the treated soil was 0.102°. The residuary effect of the treatment is quite persistent.

Another series was run in which the water content of the washed soils was lower, or approximately the so-called optimum point. The concentration of the solution in the soil was not determined until the end of a 30-day period. At that time the freezing-point lowerings of the soils were great and not strikingly different from those of the high water series. The results of this experiment are given in Table III.

TABLE III.—*Effect of calcium sulphate on the solubility of washed soils held at low water content for 30 days*

Soil No.	Condition of soil.	Freezing-point depressions.
		°C.
1	Treated	0.103
	Untreated	.015
2	Treated	.085
	Untreated	.010
3	Treated	.111
	Untreated	.013
4	Treated	.163
	Untreated	.007
5	Treated	.099
	Untreated	.023
6	Treated	.096
	Untreated	.023

Inasmuch as acid phosphate contains both calcium sulphate and calcium phosphate, a series was run in which the soils were treated with a saturated solution of calcium sulphate, a *N*/10 calcium phosphate, and also a combination of the two. After treatment the soils were washed as in the series described above and let stand at the high water content 30 days. At the close of the period the concentration of the soil solution was determined by the freezing-point method. The results are given in Table IV.

TABLE IV.—*Effect of calcium sulphate and calcium phosphate alone and in combination on the solubility of soils after 30 days*

Kind of soil and treatment.	Freezing-point depressions.
	°C.
Sandy loam:	
Treated with calcium sulphate	0.134
Treated with calcium sulphate and calcium phosphate	.094
Treated with calcium phosphate	.028
Untreated	.035
Silt loam:	
Treated with calcium sulphate	.096
Treated with calcium sulphate and calcium phosphate	.084
Treated with calcium phosphate	.032
Untreated	.042

A glance at the data composing Table IV reveals that the calcium sulphate in the presence of the calcium phosphate is somewhat less active in changing the rate of solubility of these soils than it is when used alone. Moreover, where the calcium phosphate alone is added to the soils the solubility is somewhat lessened. This is in accord with the results reported by Bouyoucos.[1]

[1] BOUYOUCOS, George J. RATE AND EXTENT OF SOLUBILITY OF SOILS UNDER DIFFERENT TREATMENTS AND CONDITIONS. Mich. Agr. Exp. Sta. Tech. Bul. 44, 49 p. 1919.

The results cited above immediately raise the question as to whether the great increase in concentration of the soil solution resulting from treatment with calcium sulphate is due to a stimulation of biological activities or to chemical reactions. To throw some light on this question experiments were undertaken in which the rate of production of carbon dioxid was measured. The method of procedure was as follows: The soils were allowed to stand over night in a saturated solution of calcium sulphate. They were then filtered and washed with distilled water until the concentration of the soil solution, when the soils were just saturated, was only a few parts per million. The soils were then allowed to dry. After thorough mixing, 60 gm. were weighed into 4-ounce bottles. The desired amount of water was then added and the bottles stoppered with rubber stoppers fitted with tubing so arranged that a current of air could be readily drawn through the soil. The bottles were stored in the dark at room temperature, and every 10 days the carbon dioxid was swept out by means of a current of air free from this substance, and the amount of carbon dioxid was determined. Samples of untreated soil were prepared in a similar manner and the carbon dioxid determined as outlined. Tables V and VI show the milligrams of carbon dioxid produced during the 10-day periods and also the total production for the 30-day period at the water contents used.

TABLE V.—*Effect of calcium sulphate on the production of carbon dioxid at high water content*

Soil No.	Treatment.	Carbon dioxid produced in—			Total carbon dioxid produced.
		10 days.	20 days.	30 days.	
		Mgm.	*Mgm.*	*Mgm.*	*Mgm.*
1	Calcium sulphate	3.74	9.24	7.26	20.24
	No treatment	8.14	9.02	5.72	22.88
2	Calcium sulphate	5.06	7.48	7.26	19.80
	No treatment	7.26	8.80	7.04	23.10
3	Calcium sulphate	5.94	9.90	8.14	23.98
	No treatment	7.92	11.88	9.68	29.48
4	Calcium sulphate	5.28	7.04	5.94	18.26
	No treatment	3.74	7.04	7.04	17.82
5	Calcium sulphate	9.02	12.76	13.20	34.98
	No treatment	5.94	10.34	8.80	25.08
6	Calcium sulphate	9.24	12.76	11.88	33.88
	No treatment	11.00	13.42	10.56	34.98

TABLE VI.—*Effect of calcium sulphate on the production of carbon dioxid at low water content*

Soil No.	Treatment.	Carbon dioxid produced in—			Total carbon dioxid produced.
		10 days.	20 days.	30 days.	
		Mgm.	*Mgm.*	*Mgm.*	*Mgm.*
1	Calcium sulphate	3.96	3.52	2.86	10.34
	No treatment	8.14	6.16	4.84	19.14
2	Calcium sulphate	4.40	3.30	3.30	11.00
	No treatment	7.81	5.06	4.40	17.27
3	Calcium sulphate	2.64	2.20	1.70	6.54
	No treatment	8.58	6.16	5.28	20.02
4	Calcium sulphate	3.30	2.64	2.42	8.36
	No treatment	5.50	3.52	2.86	11.88
5	Calcium sulphate	7.26	6.16	5.28	18.70
	No treatment	9.90	7.48	6.60	23.98
6	Calcium sulphate	6.38	5.72	4.62	16.72
	No treatment	10.78	7.26	5.28	23.32

At the high water content the production of carbon dioxid for the first 10-day period was depressed slightly in four soils by the treatment with sulphate, but in two soils it was stimulated. During the second period three of the untreated samples of soil still showed a slightly greater rate of production of carbon dioxid than the corresponding treated samples, and one of the treated samples of soil produced somewhat more of this material than the untreated. The remaining soils showed very slight differences in the production of carbon dioxid. During the third period there were more variations, two untreated samples producing more gas than the corresponding treated samples and three treated samples showing more activity than the untreated. The total production of carbon dioxid for the 30 days was greater for the untreated samples in four cases and less in one, and one soil showed practically no difference.

Without exception the untreated samples maintained at low water content showed a greater production of carbon dioxid for each period than the corresponding treated samples. In some instances the difference was so small as to be negligible, while in others it was very great. In every case the total production for 30 days was decidedly greater for the untreated samples.

It would appear from the data presented that the biological activities do not account for the changes in the solubility of the soils when treated with calcium sulphate, if the carbon-dioxid production may be taken as a measure. On the whole, there was a slight depression of such activities, especially when the samples were maintained at the low water content. This is somewhat at variance with the results reported by Fred and Hart,[1] who found an increased production of carbon dioxid from soil

[1] FRED, E. B., and HART, E. B. THE COMPARATIVE EFFECT OF PHOSPHATES AND SULPHATES ON SOIL BACTERIA. Wis. Agr. Exp. Sta. Research Bul. 35, p. 35-66, 6 fig. 1915.

containing 0.25 and 0.5 per cent calcium sulphate. It should be borne in mind, however, that the method of treating the samples was quite different from that in the experiment here reported. Several investigators have also reported a slight stimulation in ammonia production as a result of treatment with small amounts of calcium sulphate. In none of these experiments, however, were the soils thoroughly washed after treatment with the sulphate, and consequently it does not seem to be justifiable to make direct comparisons with our results.

At the expiration of 30 days the concentration of the soil solution of the samples maintained at the high water content was determined by thoroughly stirring the sample, withdrawing a portion to a freezing-point tube, and making the determination in the usual manner. Sufficient water was added to the samples maintained at the low moisture content to bring them up to that of the corresponding samples maintained at the high water content. The results of these determinations, together with the parts per million of soluble material, are presented in Tables VII and VIII.

TABLE VII.—*Effect of calcium sulphate on the solubility of soils held at high water content for 30 days*

Soil No.	Treatment.	Freezing-point depressions.	Soluble material.
		°C.	*P. p. m.*
1	Calcium sulphate	0.101	2,525
	No treatment	.026	650
2	Calcium sulphate	.073	1,825
	No treatment	.011	275
3	Calcium sulphate	.066	1,650
	No treatment	.014	350
4	Calcium sulphate	.184	4,600
	No treatment	.017	425
5	Calcium sulphate	.070	1,750
	No treatment	.063	1,575
6	Calcium sulphate	.098	2,450
	No treatment	.042	1,050

TABLE VIII.—*Effect of calcium sulphate on the solubility of soils held at low water content for 30 days*

Soil No.	Treatment.	Freezing-point depressions.	Soluble material.
		°C.	*P. p. m.*
1	Calcium sulphate	0.103	2,575
	No treatment	.015	375
2	Calcium sulphate	.085	2,125
	No treatment	.010	250
3	Calcium sulphate	.111	2,775
	No treatment	.013	325
4	Calcium sulphate	.163	4,075
	No treatment	.007	175
5	Calcium sulphate	.099	2,475
	No treatment	.023	575
6	Calcium sulphate	.096	2,400
	No treatment	.023	575

The total quantity of soluble material formed during the 30 days does not coincide with the amount of the carbon dioxid produced. The data show the treated samples to contain many times the amount of soluble material found in the corresponding untreated samples. There is one exception to this in the case of soil 5 at the high water content, where the treated sample contained only 175 parts per million more of soluble material than the untreated. It must be concluded, therefore, that the increase in soluble material takes place without the evolution of increased amounts of carbon dioxid and therefore is presumably due to other than biological agencies.

SUMMARY AND CONCLUSIONS

Six different soils were treated with a saturated solution of calcium sulphate. In one series of experiments the mass was transferred to filter paper, permitted to drain, and then transferred to containers and the rate of formation of soluble substances determined by means of the freezing-point method. The treatment was found to have increased the solubility of the soil to an appreciable extent.

In another series the amount of soluble material was reduced to a minimum by washing with distilled water, and the residuary effects of the treatment on the solubility were likewise determined. The calcium-sulphate treatment was found to have resulted in a very large increase in the rate of formation of soluble substances. The effects were great even when the soils were washed the second time. Obviously the treatment results in changes in the composition of the soil mass—in other words, a soil of different properties is formed. It seems that it is possible to alter the composition of the soil solution and that whether such change will have any effect on plant growth or not or whether the effect will be favorable or unfavorable will depend upon the nature of the soil and of the substances added. Moreover, it is probable that this phase of the subject has not received sufficient attention in connection with our field experiments.

Two soils of somewhat different texture and organic content were treated with a saturated solution of calcium sulphate, a *N*/10 solution of calcium phosphate, and a combination of the two. The soils were washed, and the rate of formation of soluble salts was determined. The calcium sulphate markedly increased the solubility in each soil, while the calcium phosphate decreased the rate of formation of soluble substances. When calcium phosphate was used in conjunction with calcium sulphate, it counteracted the effects of the latter to some extent.

If the carbon dioxid produced, as determined by the methods used, is taken as a measurement of the biological activities, the increase in the rate of formation of soluble substances brought about by the calcium-sulphate treatment is due mainly to other causes.

FURTHER STUDIES ON THE INFLUENCE OF HUMIDITY UPON THE STRENGTH AND ELASTICITY OF WOOL FIBER [1]

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INTRODUCTION

In a previous issue of the Journal the author published a preliminary report [2] of his work on the influence of humidity upon the strength and elasticity of wool fiber. An attempt was made to obtain a better method of testing wool in order that wool from sheep under various conditions of breeding, feeding, and range management might be satisfactorily tested. A study was also made upon the strength and elasticity of wool in an unscoured state under various conditions of humidity. A review of the literature was given in the earlier report and will not be repeated at this time.

EXPERIMENTAL WORK

After the work referred to above had been completed, further studies were begun upon scoured wool. As in the previous work, all samples were tested with a McKenzie fiber-testing machine. Wherever diameters are reported they are the results of measurements with a micrometer caliper unless otherwise stated. This micrometer had a ratchet stop and was graduated to read in hundredths of a millimeter. The micrometer was used in the lower jaw of the testing machine and had a small hand lens held stationary before it. With this arrangement it was possible to interpolate the readings to 0.001 mm. The diameters of the fibers were read at four different points. The smallest of these figures was in each case used in computing the tensile strength of the wool fiber.

Samples 991, 994, 996, and 997 had been extracted with ether and washed with hot water and tested at each of five relative humidities, 40, 50, 60, 70, and 80 per cent, when the operator was suddenly called into military service. The results of this work are given in Tables I and II.

TABLE I.—*Tensile strength of wool fiber at five different humidities*

Sample No.	Number of fibers.	At relative humidity of—				
		40 per cent.	50 per cent.	60 per cent.	70 per cent.	80 per cent.
		Mgm.	*Mgm.*	*Mgm.*	*Mgm.*	*Mgm.*
991	100	279. 22	299. 47	289. 85	264. 29	258. 02
994	100	274. 77	280. 50	279. 73	255. 22	269. 59
996	100	295. 64	302. 00	281. 47	281. 40	271. 83
997	100	215. 34	210. 48	201. 87	200. 67	196. 56
Average		266. 24	273. 11	263. 24	250. 39	249. 00

[1] Approved for publication in the Journal of Agricultural Research by the Director of the Agricultural Experiment Station of the University of Wyoming.

[2] HARDY, J. I. INFLUENCE OF HUMIDITY UPON THE STRENGTH AND THE ELASTICITY OF WOOL FIBER. *In* Jour. Agr. Research, v. 14, no. 8, p. 285–296, 2 fig., pl. 48, 1918. Literature cited, p. 294–295.

TABLE II.—*Elasticity of wool fiber at five different humidities*

Sample No.	Number of fibers.	At relative humidity of—				
		40 per cent.	50 per cent.	60 per cent.	70 per cent.	80 per cent.
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
991	100	27. 80	29. 08	28. 48	29. 24	30. 04
994	100	28. 64	30. 92	31. 08	31. 32	34. 20
996	100	34. 32	38. 32	38. 28	40. 36	37. 40
997	100	24. 20	25. 28	27. 28	27. 00	26. 48
Average		28. 74	30. 90	31. 28	31. 98	32. 03

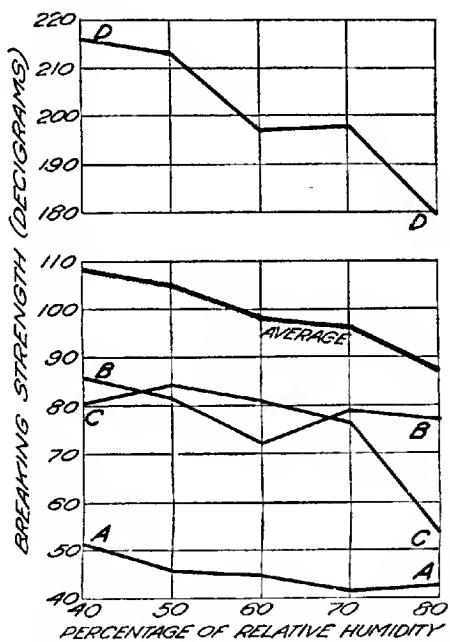

FIG. 1.—Graphs showing the effect of humidity upon the breaking strength of wool fiber.

Table I shows an average increase in the tensile strength of scoured wool as the humidity is raised from 40 to 50 per cent, and a decrease as the humidity is raised from 50 to 80 per cent. In Table II the average percentage of elasticity is shown to increase as the humidity is raised from 40 to 80 per cent.

A new operator was put upon the work in order to obtain more data under the same conditions and additional data on fibers of a smaller diameter. The diameter of the fibers of sample 991 averaged 0.016 mm.,

while samples 994, 996, and 997 had an average diameter of 0.026, 0.029, and 0.025 mm., respectively. There was one sample of wool with an average diameter of fibers less than 0.02 mm., and there were three samples with the average diameter above that figure.

The new set of samples chosen, A, B, C, and D, consisted of four samples with average diameters of 0.012, 0.018, 0.017, and 0.031 mm., respectively. Three of these samples were under 0.02 mm. in diameter, and one was larger. The range in average diameter of the fibers tested is from 0.012 to 0.031 mm. Fibers were tested from small locks of scoured wool from samples A, B, C, and D until 200 fibers were tested at each of

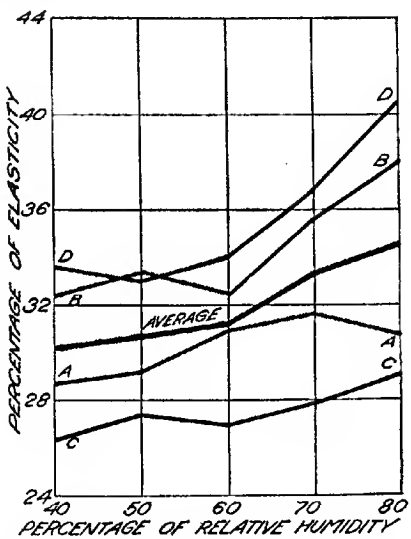

FIG. 2.—Graphs showing the effect of humidity upon the elasticity of wool fiber.

five humidities, as shown in Table III. It will be noted that the breaking strength of the fibers decreases quite uniformly as the humidity increases. Sample D shows a decrease in its tensile strength as the humidity increases up to 80 per cent, when there is a very slight increase. In A, B, and C the tensile strength seems to fluctuate up and down with no particular uniformity. These values for tensile strength were much more variable than those for the breaking strength. Several hundred additional fibers were tested on A, B, C, and D at humidities of 40 and 50 per cent, since the greatest variability seemed to occur at these two points. Graphs showing the values obtained on these samples of scoured wool for breaking strength and elasticity are shown in figures 1 and 2.

TABLE III.—*Diameter, breaking strength, and tensile strength of scoured wool fibers at five different humidities*

Sample No.	At relative humidity of 40 per cent.					At relative humidity of 50 per cent.				
	Diameter in thousandths of a mm. (average of 100).	Breaking strength (average of 100).	Average.	Tensile strength per thousandth of a sq. mm.		Diameter in thousandths of a mm. (average of 100).	Breaking strength (average of 100).	Average.	Tensile strength per thousandth of a sq. mm.	
				Average of 100.	Average of 200.				Average of 100.	Average of 200.
		Dgm.	*Dgm.*	*Mgm.*	*Mgm.*		*Dgm.*	*Dgm.*	*Mgm.*	*Mgm.*
A	11.9	48.59	48.56	433.97	396.65	10.79	47.67	45.39	521.67	466.88
	13.2	48.52	.....	359.33	.....	11.54	43.10	.....	412.08	.....
B	20.04	86.62	89.33	274.37	279.49	17.86	82.81	86.17	330.37	324.87
	20.34	92.04	.....	284.60	.....	18.83	89.52	.....	319.36	.....
C	19.89	88.03	85.28	283.29	301.96	17.40	82.89	81.21	349.05	341.80
	17.44	82.52	.....	320.63	.....	17.40	79.53	.....	334.54	.....
D	30.78	208.02	209.68	281.50	280.94	32.57	221.86	214.54	266.54	267.64
	30.48	211.32	.....	280.38	.....	31.36	207.22	.....	268.74	.....

Sample No.	At relative humidity of 60 per cent.					At relative humidity of 70 per cent.				
	Diameter in thousandths of a mm. (average of 100).	Breaking strength (average of 100).	Average.	Tensile strength per thousandth of a sq. mm.		Diameter in thousandths of a mm. (average of 100).	Breaking strength (average of 100).	Average.	Tensile strength per thousandth of a sq. mm.	
				Average of 100.	Average of 200.				Average of 100.	Average of 200.
		Dgm.	*Dgm.*	*Mgm.*	*Mgm.*		*Dgm.*	*Dgm.*	*Mgm.*	*Mgm.*
A	12.84	44.89	44.90	407.40	379.74	10.80	41.09	40.31	455.25	432.26
	12.75	44.91	.....	352.07	.....	11.09	39.53	.....	409.27	.....
B	16.44	72.85	72.30	343.30	336.41	18.85	85.86	79.97	324.14	329.28
	16.55	71.74	.....	329.51	.....	16.85	74.08	.....	334.41	.....
C	18.37	81.02	81.02	305.68	305.68	16.57	74.62	76.93	347.26	346.77
	.....	.....	.....	.....	.....	17.08	79.23	.....	345.78	.....
D	30.65	197.02	197.02	266.27	266.27	31.26	199.67	196.49	260.07	263.64
	.....	.....	.....	.....	.....	30.35	193.31	.....	267.20	.....

Sample No.	At relative humidity of 80 per cent.				
	Diameter in thousandths of a mm. (average of 100).	Breaking strength (average of 100).	Average.	Tensile strength per thousandth of a sq. mm.	
				Average of 100.	Average of 200.
		Dgm.	*Dgm.*	*Mgm.*	*Mgm.*
A	11.97	45.41	42.95	403.85	437.92
	10.45	40.48	.....	471.98	.....
B	17.26	73.79	79.94	315.37	315.05
	18.64	86.08	.....	314.72	.....
C	13.62	51.46	53.78	353.21	343.32
	14.65	56.10	.....	333.42	.....
D	30.02	183.75	179.79	259.60	265.92
	28.69	175.83	.....	272.24	.....

The heavy line shows the average values obtained for all the results secured at each humidity. The average breaking strengths of these samples of scoured wool decrease as the humidity increases, while the elasticity shows an increase with an increase in humidity.

The wide variations in the values for tensile strength as compared with similar values for breaking strength led the writer to compare the tensile strengths of fibers of different diameters in locks of wool A, B, and D.

Graphs showing the variation in the tensile strengths of three different samples of wool are shown in figure 3 in the curves A–A, B–B, and D–D.

The fibers tested in these curves range from 0.008 to 0.038 mm. in diameter. The number of fibers tested at each humidity varies considerably. In some cases only 30 or 40 were tested, while in other cases as many as 250 of a given diameter were tested. Sample A of curve A–A ranges in fineness from 0.008 to 0.018 mm. The tensile strength decreases from 667 to 260 mgm. per thousandth of a square millimeter at the lowest point. Sample B shows a decrease from 466 mgm. at 0.01 mm. to 315 mgm. at 0.022 mm. The curve of sample B follows that of sample A very closely from a diameter of 0.01 mm. to one of 0.018 mm. and rises slightly from a diameter of 0.018 mm. to one of 0.022 mm. Sample D decreases from 320 mgm. at 0.023 mm. to 232 mgm. at 0.038 mm.

These curves show that the tensile strength of wool decreases with an increase in diameter. The drop is most abrupt with the sample of fine wool. The coarsest sample has the most gradual drop in its diameter and tensile strength curves. If the breaking strength of wool varied directly as the area of cross section, the curve would follow the line E–E. If the breaking strength varied as the diameter or circumference, the tensile strength curve would follow the line F–F. The curve for the tensile strength of sample D follows the line D–D and lies between these two lines E–E and F–F. This fact seems to indicate that the breaking strength of medium and coarse wool varies with some power of the diameter which lies somewhere between the first and second.

For fine wool like sample A, a curve showing the strength of the wool very closely follows a curve plotted with 1, or any constant, and the first power of the diameter. This fact indicates that the breaking strength of fine wool does not vary directly with the area of the cross section but with a value which is very close to the first power of the diameter. Curve C–C shows the relation between the tensile strengths and diameters of wool fibers obtained from data published by Hill.[1] In the present experiment, 1,000 fibers were broken to obtain the points in this curve, and each diameter was measured after breaking as nearly as possible at the point of breakage. This curve also follows very closely the curve F–F. By inspecting the graphs it is easy to see that the widest variations in the curve F–F plotted from $\frac{1}{D}$ are found at the smallest diameters. As this curve approaches the larger diameters it tends to become rather flat.

In the first three samples of Table III there is a large variation between the largest and smallest tensile strengths of the wool fibers of those samples. When fibers are tested with such a wide variation in their tensile strength as is found in locks of fine wool, it is necessary that these fibers be carefully mixed in order to get satisfactory results. There is a tendency for an operator to pull the largest fibers in fine wool, while with

[1] HILL, J. A. STUDIES ON THE STRENGTH AND ELASTICITY OF THE WOOL FIBER. I. THE PROBABLE ERROR OF THE MEAN. *In* Wyo. Agr. Exp. Sta. 21st Ann. Rpt., 1910–11, suppl., 139 p. 1911.

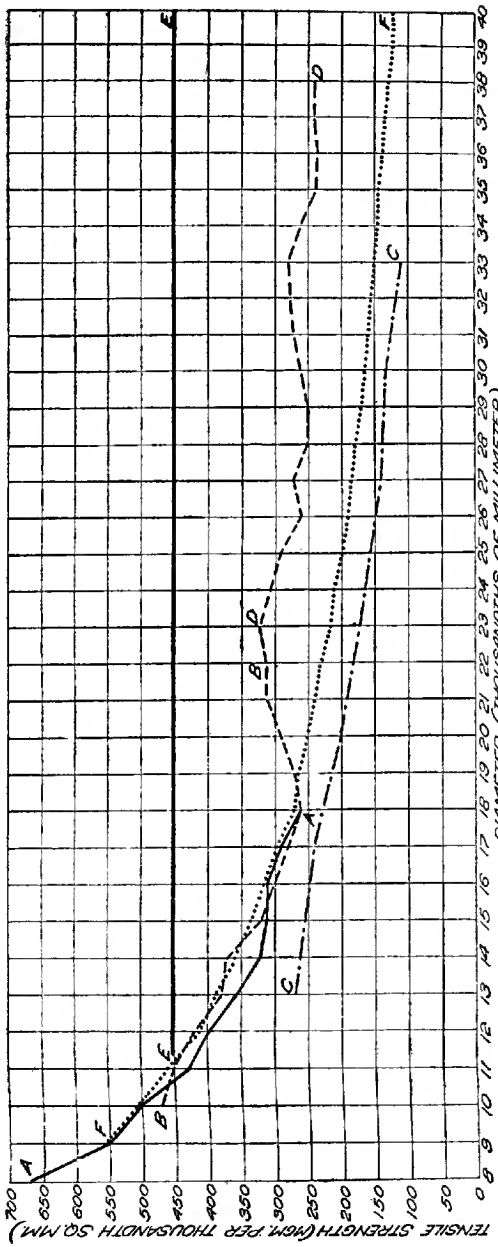

FIG. 3.—Graphs showing the relation between the diameter and the tensile strength of wool fiber.

coarser samples there is not such a tendency. This fact and the fact that larger fibers can be more accurately measured with a micrometer caliper make it possible to get satisfactory results for tensile strengths with samples of coarser wools. Then again the coarser wools have breaking strengths which vary more closely with the areas of the cross section of the wool than do the breaking strengths of fine wool samples, as is shown in F–F of figure 3. The coarse wools may be measured from the original lock, and their breaking and tensile strengths may be determined quite satisfactorily.

Sometimes it is necessary to make the closest possible comparison of the effects of various conditions or chemical reagents on a given grade of wool, as in the case at hand. The writer desired to determine the effects of various humidities upon a uniformly mixed sample of wool. Single fibers were drawn from sample B and placed consecutively in six different groups, numbered 1 to 6, with their ends extending from one piece of adhesive tape to another which was laid parallel to it and about 2¾ inches from it. Always beginning with No. 1, these fibers were placed one at a time in each of these six groups until 100 fibers, or the desired number, were in each of the six small locks. By making five series of these groups and subjecting the same numbers of each group to the same test, it is possible to get some very satisfactory comparisons. Although it is very tedious work, these fibers may be picked out by hand at the rate of 200 an hour. Five small locks, each containing 120 fibers, were tested in the scoured condition at humidities of 40, 50, 60, 70, and 80 per cent and saturated. Similar locks were scoured with ether and hot water and tested under the same conditions. The saturated fibers were kept between moist filter papers until tested.

Table IV and figure 4 show the results of this experiment.

TABLE IV.—*Elasticity and breaking strength of scoured and unscoured wool from sample B*

[Average of 600 fibers]

Percentage of humidity.	Scoured wool.		Unscoured wool.	
	Elasticity.	Breaking strength.	Elasticity.	Breaking strength.
	Per cent.	*Dgm.*	*Per cent.*	*Dgm.*
40	25. 80	65. 14	26. 40	69. 06
50	30. 76	64. 11	31. 48	68. 97
60	33. 96	64. 64	34. 72	67. 01
70	37. 08	59. 53	38. 00	63. 80
80	40. 08	60. 10	43. 64	60. 44
Saturated	33. 76	59. 16	34. 60	63. 42

The curve for unscoured wool shows that the breaking strength decreases as the relative humidity changes from 40 to 80 per cent and increases when the wool becomes saturated. In scoured wool the curve is more irregular. There is a definite drop as the humidity changes from

40 to 80 per cent, although the curve makes almost a straight line from 70 per cent up to the point of saturation. The elasticity curves for scoured and unscoured wool are nearly parallel, rising as the humidity changes from 40 to 80 per cent and falling from this point to that of saturation.

SUMMARY

(1) The tensile strength of wool increases with the decrease in the diameter of the wool fiber.

(2) Fine wool has a breaking strength varying more closely with the first than with the second power of the diameter.

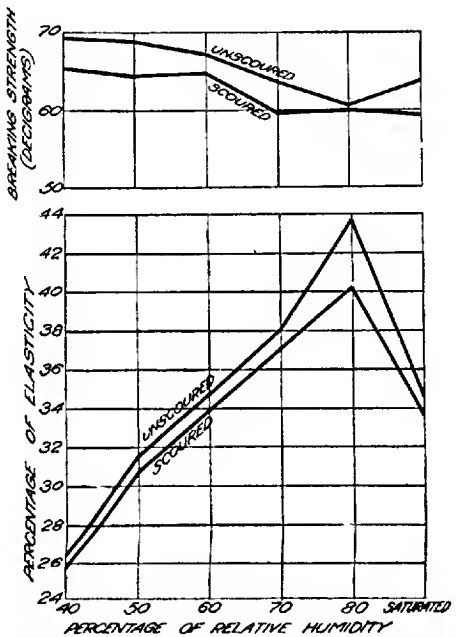

FIG. 4.—Graphs showing the effect of humidity upon the breaking strength and elasticity of wool fiber.

(3) Coarse wool has a breaking strength varying with a figure which lies somewhere between the first and second powers of the diameter.

(4) It is necessary to mix samples of fine wool carefully before testing in a testing machine if the best results are to be obtained.

(5) The breaking strength and tensile strength of both scoured and unscoured wool decrease with an increase in relative humidity from 40 to 80 per cent and show a tendency to increase from this point to that of saturation.

(6) The elasticity of scoured and unscoured wool increases with an increase in relative humidity from 40 to 80 per cent and decreases from this point to that of saturation.

COMPOSITION AND DENSITY OF THE NATIVE VEGETATION IN THE VICINITY OF THE NORTHERN GREAT PLAINS FIELD STATION

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INTRODUCTION

The grazing industry in the Northern Great Plains area is intimately concerned with the composition and density of the native vegetation. This paper deals with the native vegetation as it exists at present in the section under consideration. While parts of the discussion will apply in general to the Great Plains area, it pertains to western North Dakota and in particular to the territory adjacent to the Missouri River on the west near Mandan. This point lies practically on the one hundred and first meridian and just south of the forty-seventh parallel, north latitude. The Bureau of Plant Industry has one of a number of field stations located here under the direction of the Office of Dry-Land Agriculture. One of the lines of investigation in connection with this station is a grazing experiment in cooperation with the North Dakota State Experiment Station. This investigation is primarily concerned with determining the carrying capacity of the range in that section and working out a grazing system adapted to conditions in the Great Plains. In connection with this work it is necessary to make detailed studies of the native vegetation in order to observe any changes that may occur in the structure of the plant cover. These studies have furnished the material of this paper.[1]

TOPOGRAPHY AND SOIL

The topography of the area around Mandan varies from rolling to nearly level. The land is cut by numerous ravines and coulees, which drain into the Heart and Missouri Rivers. The altitude of the field station is approximately 1,700 feet above sea level.

The following description of the soil of this area is quoted from "The Story of the Prairies" by Willard (*9*),[2] formerly geologist at the North Dakota Agricultural College:

A belt having an indefinite edge to the westward lies along the west side of the Missouri River, which belt represents the western limits of the glaciated area of North Dakota, and of the Continent of North America. This "belt" of land along the west

[1] The annual reports by the author of the cooperative grazing experiment at Mandan have been frequently referred to and used in the preparation of this paper. These reports are on file in the Office of Dry-Land Agriculture, the North Dakota Agricultural College, and the Mandan Field Station.

[2] Reference is made by number (italic) to "Literature cited," p. 71-72.

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side of the river shows by the character of the soils and the rocks that lie upon or near the surface that the great continental glacier was once here. Toward the west the belt fades out and becomes indistinguishable from the land farther west over which the ice did not pass, but the eastern part of the belt is sufficiently modified as to the soils and the landscape features to be readily recognized.

The soils, therefore, in the belt bordering the Missouri River on the west constitute a transition type from the glacial soils of the eastern portion of the State to the non-glaciated or residual soils of the southwestern portion of the State.

CLIMATE

The United States Weather Bureau Station at Bismarck has made continuous meteorological observations since 1875. Bismarck is located on the east side of the Missouri River, only about 5 miles distant from Mandan. Observations were begun at the Mandan Field Station during 1913. From 1875 to 1914, inclusive, or 40 years, the mean annual precipitation was 17.41 inches. The greatest annual amount during this period was 30.92 inches in 1876, while the lowest was 11.03 inches in 1899. During 1917 the record at the Mandan Field Station was 10.31 inches. The mean seasonal precipitation from April 1 to July 31, inclusive, was 9.91 inches during the 40-year period. The month of maximum precipitation is June, with a mean of over 3.5 inches, and the month of minimum precipitation is February, with less than 0.5 inch.

The temperature is extreme in both winter and summer. The lowest recorded to date was 45° F. below zero in January, 1916, while the highest was 107° above zero in July, 1910 and 1917. The average dates of killing frosts in spring and autumn are about May 15 and September 15, respectively, but frosts have occurred as late as June 7 and as early as August 23. The average frost-free period is 128 days. The prevailing wind direction is from the northwest. The average wind movement near the ground is about 6 miles per hour.

PLANT FORMATION

According to a map of "Plant Formations of the United States," by Shantz and Zon,[1] this region would come within the "short-grass formation." However, Dr. F. E. Clements, who visited the field station during the summer of 1917, is of the opinion that it would be more properly placed in the "long-grass" or "prairie formation," because of the long grasses and other plants which are typical of a prairie formation. From actual determinations in the field the percentages of short-grass and long-grass cover have been found to be nearly equal, so that the formation could be put in either class, according to the viewpoint of the observer. If the secondary plant layer is considered as the determining factor, the region falls in the long-grass formation. The vegetation in this particular area might be considered as in a transition zone, since the dominating species are typical of both formations.

[1] SHANTZ, H. L., and ZON, R. PLANT FORMATIONS OF THE UNITED STATES. Paper presented before the Ecological Society of America at its annual meeting in New York in 1916. The map will appear in the Agricultural Atlas.

The dominating species are *Bouteloua gracilis* (*B. oligostachya*) and *Stipa comata*, which form a distinct association. This is an association composed of *Bouteloua gracilis*, which is typical of the short-grass formation, and *Stipa comata*, which is a typical long-grass species. This association is dominated by the Bouteloua. Sarvis[1] has described in a paper other sections of western North Dakota which show the same dominating species.

COMPOSITION OF THE VEGETATION

In Plate 12 is illustrated the general character of the vegetation on the prairie in the Mandan region. In 1915, when this photograph was taken, the season was very favorable, and all plants reached a maximum development. The composition of the vegetation is thus very clearly illustrated.

In the following list of plants the arrangement of species is in the order of abundance. The order of the primary and secondary species is subject to slight modifications as the studies are extended. The order of the dominant species was determined by measurements from quadrat maps and in the field. The order of the primary species, other than grasses, was determined by count. The secondary species are listed in the estimated order of their abundance.

DOMINANT SPECIES

Bouteloua gracilis
Stipa comata
Carex filifolia
Carex heliophila

PRIMARY SPECIES

Artemisia gnaphalodes
Koeleria cristata
Solidago pulcherrima
Agropyron smithii
Artemisia dracunculoides
Psoralea argophylla
Andropogon scoparius
Artemisia frigida
Stipa viridula
Eschinacea angustifolia
Aristida longiseta
Polygala alba
Stipa spartea
Ratibida columnaris

SECONDARY SPECIES

Muhlenbergia cuspidata
Lacinaria punctata
Calamovilfa longifolia
Agropyron caninum
Bouteloua curtipendula
Comandra pallida
Aster multiflorus
Petalostemon purpureum
Petalostemon candidum
Lactuca pulchella
Vicia sparsifolia
Agropyron tenerum

The grasses, other than the dominant species, are in the estimated order of abundance. It is difficult to make individual counts of them, since they usually occur in bunches. If bunches or mats were considered as single plants and enumerated as such the number would have no significance when compared with that of other plants which usually occur as individuals.

[1] SARVIS, J. T. NATIVE GRASSES OF WESTERN NORTH DAKOTA. Paper presented before the Ecological Society of America at its annual meeting in New York in 1916.

When the vegetation is considered from the standpoint of grazing, only a very few species are important factors in the total amount of forage annually produced. Sampson (6) has discussed this point more fully. In this region, *Bouteloua gracilis* and *Stipa comata* are the most important species, both on account of their total forage production and their value as grazing grasses.

The value of a given species for grazing purposes depends upon (1) its abundance, (2) whether it is relished by stock, (3) its length of growing season, (4) its ability to withstand trampling and to recover readily from grazing, and (5) its adaptation to drought conditions. According to these requirements, *Bouteloua gracilis* would take first rank and *Stipa comata* would be second in importance.

A plant may be of importance in relation to grazing because of its abundance, whether it is or is not of grazing value. If it is a valuable grazing species it is of primary importance, and if it is of minor grazing value it is of importance because it occupies ground surface that might otherwise support a more valuable species. On the other hand, a species may be greatly relished by stock, as *Andropogon furcatus* at Mandan, but occur in such limited areas that it is unimportant in the total amount of forage annually produced. In pastures where this grass occurs it is cropped close to the ground throughout the season, as illustrated in Plate 13, A.

Bouteloua gracilis is grazed with avidity at all times of the year. It cures well on the ground without great loss of its nutritive value, and late in the fall cattle eat it in preference to any other grass. Although *Stipa comata* has the disadvantage, for a short period, of its sharp needles, it is so much more abundant than other species, except *B. gracilis*, that it enters largely into the feed of grazing animals. It is the first grass to produce green shoots in the spring, and it usually produces more growth late in the fall than do other species.

A grass that is similar in appearance and often confused with *Bouteloua gracilis* is *Bulbilis dactyloides*, or buffalo grass. It has a better reputation for grazing and is more widely known by a popular name than any other single species of grass in the Great Plains. However, out of several thousand acres of native vegetation surrounding the field station, there are less than 5 acres of the true buffalo grass. On a trip over western North Dakota in the summer of 1916, the author found this grass in only a few small areas. Blue grama (*Bouteloua gracilis*) is and always has been called buffalo grass by the people in the Great Plains area. This misnomer has been and is so universal that it is difficult to obtain reliable information concerning the abundance and importance of buffalo and blue grama grasses for grazing in the early history of the range. However, at present the true buffalo grass occurs only in small amounts in this region and in western North Dakota, where it is evident it never

was as abundant as in western South Dakota. Pound and Clements (4) said in regard to buffalo grass:

> The buffalo-grass was, until recently, supposed to have once covered the greater portion of Nebraska; its disappearance has, as a matter of sentiment, been connected with that of the buffalo. The patches of buffalo-grass, which are found scattered here and there over the State, are to be regarded as intrusions rather than stragglers left by a retreating species.

Griffiths (2) says in regard to *Bulbilis dactyloides:*

> *Bouteloua gracilis*, especially when not in head, is very similar and frequently mistaken for it. On this account the true buffalo grass is very much overestimated in importance, because there are so many things included with it in the popular mind. Much of the credit given this species is due to the gramas, which in age especially look much like it. On the other hand, the species is an important one throughout its range.

In southwestern South Dakota, at the Ardmore Field Station, where a grazing experiment is now being conducted, the important grazing grasses are *Bulbilis dactyloides*, *Bouteloua gracilis*, and *Agropyron smithii*. This association is dominated by the Bulbilis.

It often happens that a species that is of little grazing value in one section is of value in another area. For example, *Aristida longiseta* is of little grazing value at Mandan, since it is the last plant that cattle will take even when the pasturage is short, as illustrated in Plate 13, B. However, in other sections, Griffiths, Bidwell, and Goodrich (2) report this species as being of considerable value.

Some species are indicators of overgrazing, as *Artemisia frigida* at Mandan. In pastures where this plant occurs in abundance it usually will be found that the area has been overstocked for several seasons.

In the vegetation of this area no poisonous plants are abundant enough to be harmful. However, in areas farther west in North Dakota, the common "loco weed" (*Oxytropis lamberti*) is abundant and causes serious losses of stock in certain seasons.

All the plants mentioned in the list on page 65 enter more or less into the feed of grazing animals, but, as noted, only a few species produce a considerable percentage of the total forage. One of the reasons for this fact is the inability of many plants to produce more than a limited second growth after they have once been removed by grazing.

DENSITY OF VEGETATION

In a consideration of plant density in relation to grazing problems it is desirable and necessary to make clear and concise distinctions between frequently recurring terms. Plant density should refer to the "stand" or thickness of plants upon the ground surface. The ground surface is the total area of land under consideration, whether vegetated or unvegetated. Bare ground should be understood to refer to the unvegetated portion of the ground surface or the spaces in the cover between

individual plants or between mats and bunches of species which grow in that manner. The term cover (*8*), or ground cover (*5*), is frequently and conveniently used in connection with discussions of vegetation. However, when the term cover is applied in connection with grazing investigations it should be defined, for it may mean one of two things: (1) basal cover, or the ground surface limits of living vegetation, or (2) the foliage cover, which is the plant layers above the basal cover. When the foliage cover is removed, as by close grazing or clipping, the basal cover remains. Plant layers as described by Clements (1) are vertical zones based on the height of plants. On the prairie around Mandan two layers are important—the ground layer, as Bouteloua and Carex, and the secondary layer, as Stipa and Psoralea.

Species that grow in mats or in bunches are most accurately expressed in terms of basal cover. For example, Bouteloua basal cover would refer to the amount of ground surface actually covered by Bouteloua if the foliage were removed by grazing or clipping. In such species it is possible to make the determinations with almost mathematical precision. Species that occur as individuals are best expressed in terms of their abundance per unit area. Shantz (7) says in regard to this point:

> Those species which form mats can not be well represented in numbers per square meter, and on this account the percentage of surface covered is given instead.

The foregoing statements in regard to basal and foliage cover are very clearly illustrated in Plate 14. In 1915 the foliage cover was very heavy because growth conditions were favorable and the area had not been grazed. An estimate of the total cover based upon the amount of foliage cover could easily have been made at that time. But in 1916 on the same area, with the foliage cover removed, there would have been no basis for comparison with the 1915 condition. This illustrates the undesirability of utilizing the foliage cover, under all conditions, as a basis for estimating the possibilities of forage production and the consequent carrying capacity. A clear distinction between basal cover and foliage cover is, therefore, necessary and important. The two illustrations of Plate 14 picture the same area, but one illustrates a heavy foliage cover and the other only the basal cover. However, the potential ability of the area to produce under similar conditions as heavy a foliage cover as in 1915 is unchanged.

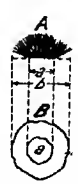

FIG. 1.—Diagram of grass mat: A, from side; B, from above. *a*, Basal cover; *b*, foliage cover.

Figure 1 illustrates the difference between the basal cover and the foliage cover. The limit of basal growth is *a*, while the limit of foliage growth is *b*. In a given case the surface area of the foliage cover is greater than that of the basal cover, yet the amount of forage is the same. The basal cover is more permanent than the foliage cover, since the latter may be readily removed by grazing. The quadrat map (fig. 2) in the 30-acre pasture, which was mapped in 1915 and remapped in 1916, shows,

with the exception of a few annual species, the basal cover to be practically the same in both years. If the maps had been drawn on the basis of the foliage cover, there would have been a great difference between the 1915 and 1916 maps. The photographs illustrate this difference more clearly than would be possible by quadrat maps. But if the maps are drawn on a basis of the basal cover, various maps of a given quadrat would show actual changes as they occur from grazing. This is really

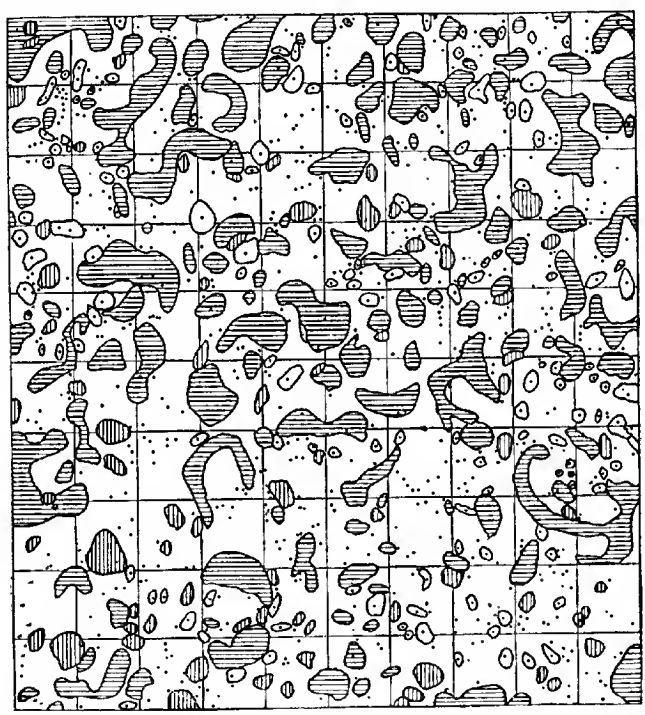

FIG. 2.—Meter quadrat in 30-acre pasture mapped in detail in 1915. Cross hatching represents *Bouteloua gracilis;* vertical hatching, *Stipa comata.* The presence of other species is indicated by dots and outlined areas.

the important point in relation to grazing systems. If grazing has been severe, the basal cover is likely to be changed rapidly, but under normal conditions it should change gradually. This is especially true in such regions as Mandan, where most of the vegetation is made up of perennial species. Sampson (5) says in regard to increase of ground cover:

> The increase in actual stand or ground covered was due almost entirely to the enlargement of the tufts, and text figures 5 and 6 show that even under season-long protection the bunch-grasses and other valuable plants do not increase rapidly by this means.

Since the carrying capacity of the range is largely dependent upon the density of the vegetation, it is obvious that this factor should be carefully determined. If density is determined on the basis of the foliage cover, even when this is possible, the carrying capacity is likely to be placed too high, because of favorable growth conditions or an accumulation of previous growth, and overgrazing will result. In normal seasons the amount of forage a given area of ground surface can produce is largely determined by its basal cover. Therefore, the basis for an estimate of the amount of ground surface covered by vegetation should be founded upon the basal cover. The foliage cover is the important consideration for immediate grazing, but the basal cover more nearly determines the future possibilities of a given area of land for grazing purposes.

AMOUNT OF BASAL COVER AT MANDAN

From quadrat maps drawn to show bare and covered ground surface the total basal cover has been determined. The maps show about 60 per cent vegetated and 40 per cent bare ground. From quadrat maps, such as that in figure 2, made in the various pastures, the percentages of basal cover of Bouteloua and Stipa were determined. These are approximately 20 and 10 per cent, respectively. These determinations were all made from the maps by means of a planimeter.

Shantz (7) has made a number of estimates on the amount of cover in a series of quadrats in the mesa region near Pikes Peak. He has expressed the amounts in percentages in each case. The same method is followed in the present studies. This is a most convenient system, especially when it is desired to express a given species in terms of amount of total cover. Sampson (5) expresses the "density of vegetation" in terms of tenths, using 10 as complete ground cover. In order to avoid confusion, the amounts of cover as used in connection with the Mandan grazing experiment are expressed in percentages.

From the amounts of basal cover of *Bouteloua gracilis* and *Stipa comata* it is readily seen how important they are from the standpoint of grazing in this section. Griffiths, Bidwell, and Goodrich (2) have discussed the value of these grasses for forage. From clipping experiments at Mandan in 1917, in connection with the grazing studies, the Bouteloua was found to have produced from 40 to 50 per cent and Stipa from 15 to 20 per cent of the total forage for the season. When the quadrats were clipped, the vegetation was separated into six parts, as follows: *Bouteloua gracilis, Stipa comata, Aristida longiseta*, other grasses, *Carex filifolia* and *C. heliophila*, and other plants. Columns are also reserved for the sum of *B. gracilis* and *S. comata* and for the total weight of all grasses and of all species. From these data it is possible to determine the relation of one species or group to another or to the total weight of all species. The various amounts were recorded in grams, weighed both green and air-dried. From these data it appears evident that the ground layer is the

The abundance of a given species often appears greater than is determined by actual counts per unit area. Pound and Clements (4) have fully discussed this point. From Plate 12 it would appear that *Psoralea argophylla* is the most abundant species. However, by a number of actual counts per unit area it was found to be fourth in abundance of plants other than grasses and sedges.

SUMMARY

(1) The data and conclusions presented in this paper have been obtained in connection with a grazing experiment at the Bureau of Plant Industry Field Station near Mandan, N. Dak. This experiment is designed to determine the carrying capacity of the native vegetation and the effects upon it of different intensities and methods of grazing.

(2) The vegetation is composed of a large number of species, only a few of which produce a considerable amount of the total forage. The dominating species are *Bouteloua gracilis* and *Stipa comata*.

(3) The density of the vegetation is determined by the thickness of plants upon the ground surface and not by the foliage growth. The term cover used in connection with density may mean basal cover or foliage cover. The former remains after the latter has been removed by close grazing or clipping.

(4) The total basal cover of all species in the Mandan region is approximately 60 per cent of the ground surface. *Bouteloua gracilis* has a basal cover of about 20 per cent and *Stipa comata* nearly 10 per cent of the ground surface.

(5) Clipping data of different day periods showed that *Bouteloua gracilis* had produced from 40 to 50 per cent and *Stipa comata* from 15 to 20 per cent of the total forage. The remainder was made up of a number of other species.

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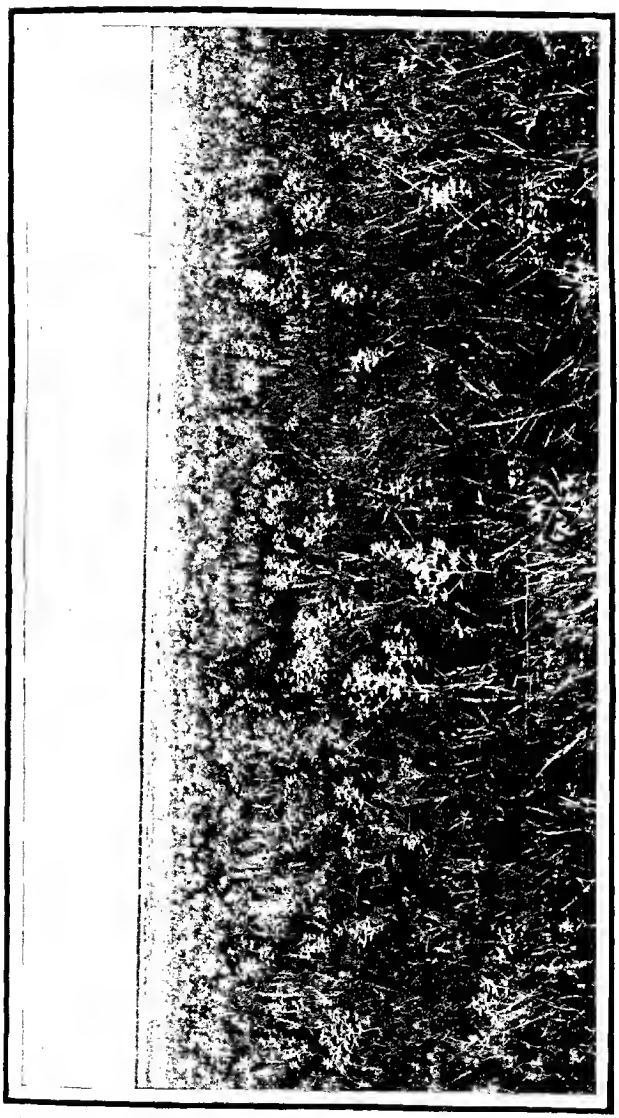
PLATE 12

General view of native vegetation near Mandan, N. Dak., showing composition and density. The following species are evident in the photograph: *Psoralea argophylla, Echinacea angustifolia, Artemisia frigida, Bouteloua gracilis, Stipa comata, S. viridula,* and *Ratibida columnaris.*



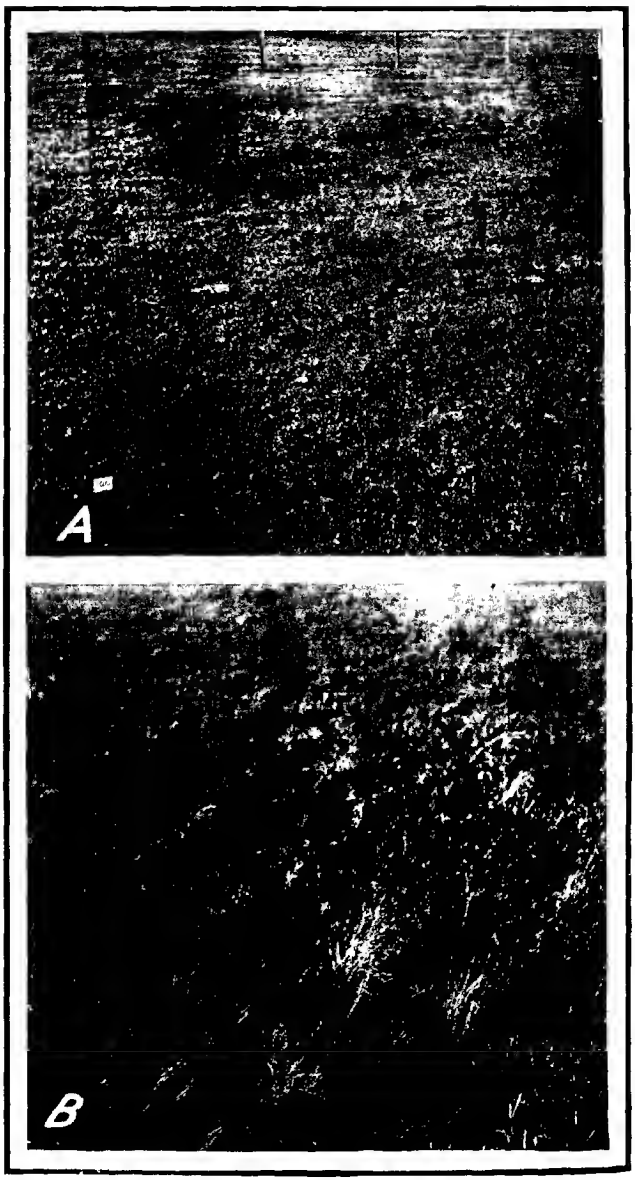

A
B

PLATE 13

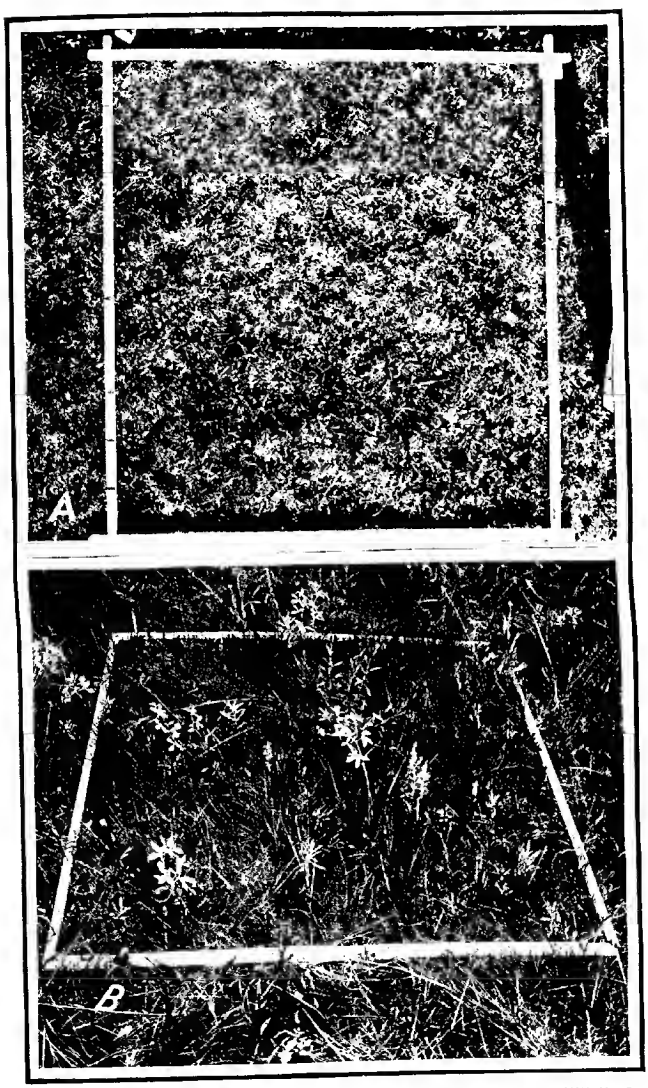
A.—View across area of *Andropogon furcatus*. This grass is closely grazed, as it is greatly relished by cattle. Mandan, N. Dak., Nov. 2, 1917.

B.—Close view of *Aristida longiseta* bunches. All other vegetation has been removed by cattle close to the bunches. Mandan, N. Dak., Nov. 2, 1917.

PLATE 14

A.—Close view, from above, of meter quadrat in 30-acre pasture. This is the same area shown in B but was taken in 1916 after the foliage cover had been removed by grazing. Only basal cover remains. Mandan, N. Dak., Oct. 10, 1916.

B.—Meter quadrat in 30-acre pasture. This shows the cover as it appeared before grazing. Mandan, N. Dak., July 28, 1915.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EFFECT OF REACTION OF SOLUTION ON GERMINATION OF SEEDS AND ON GROWTH OF SEEDLINGS

By ROBERT M. SALTER, *Soil Chemist*, and T. C. MCILVAINE, *Assistant Agronomist*, *West Virginia Agricultural Experiment Station*

INTRODUCTION

Recent investigations have emphasized the importance of the intensity factor of soil acidity. The growth of plants is more logically associated with hydrogen-ion concentration than with total acidity as measured by a soil's capacity to neutralize or absorb bases. However, other factors than the direct physiological influence of the hydrogen or hydroxyl ion upon the plant itself are undoubtedly operative in producing the effects attributed to soil reaction, these factors being either conditioned by the reaction or associated with it. Thus, indirect effects upon plant growth would be produced by: (1) The extent to which the soil's reaction is favorable for the development of soil organisms, more particularly those responsible for nitrogen transformation and nitrogen accumulation; (2) changes in the solubilities of soil constituents as affected by reaction, this applying not only to essential elements such as calcium, magnesium, potassium, and phosphorus but also to those having toxic properties, such as aluminium, manganese, and ferrous iron where increases in concentration would be expected with increase in acidity; and (3) changes produced in physical properties of soils attendant upon changes in reaction.

Although the mass of data on the relation of soil acidity to plant growth is already large, few well-defined attempts have been made to separate the individual factors concerned and study them under conditions permitting the control or elimination of other factors. The present investigation was undertaken with the aim of studying the direct physiological influence of reaction as measured by hydrogen-ion concentration upon plant growth. Solution culture was resorted to in order to control or eliminate other factors as far as possible.

EXPERIMENTAL METHODS

In the work herein reported, wheat, corn, soybean, and alfalfa seedlings were grown in a series of solution cultures having as far as possible a constant nutrient composition and osmotic concentration and varying in reaction from a hydrogen-ion concentration of approximately 1×10^{-3} to 1×10^{-8} or 2 P_H to 8 P_H.[1]

[1] In this report the P_H values of Sorensen will be used to state the reaction of the solutions, the value P_H being the negative common logarithm of the actual numerical concentration of hydrogen ions. Thus a concentration of hydrogen ions of 1×10^{-5} would correspond to a P_H value of 5.

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NUTRIENT COMPOSITION OF SOLUTIONS

The need for a basic nutrient culture of favorable physiological balance was recognized. The attempt was at first made to adjust Shive's solutions No. R5C2 and R3C3 (*24*),[1] which he found best suited to the growth of wheat seedlings, to the various reactions desired for the work by additions of the requisite amounts of an acid or base. However, because of the extensive precipitation of phosphates of calcium and magnesium in the more alkaline members of such series, these solutions were found unsuited to the work at hand.

Two series of solutions were eventually employed which varied somewhat in composition from Shive's best solutions. The maximum partial ionic concentrations in volume equivalents for the two solutions used are given in Table I, the composition of Shive's solutions being included for purposes of comparison.

TABLE I.—*Maximum ionic concentrations of solutions*

[Expressed as gram-equivalents per liter]

Kind of solution.	Na+.	K+.	½Ca++.	½Mg++.	NO_3−.	½SO_4−.	H_2PO_4−.	$H_2C_6H_5O_7$−.	Cl−.
Series A.	0.0100 to .0200	0.0360	0.0050	0.0050	0.0100	0.0050	0.0180	0.0100 to .0000	0.0050
Series B.	.0000 to .0360	.0180	.0050	.0050	.0100	.0130	.0180	.....	.0050
Shive's:									
R_5C_3	.....	.0180	.0104	.0300	.0104	.0300	.0180	.....	.....
R_3C_3	.....	.0108	.0156	.0400	.0156	.0400	.0108	.....	.....

The salts, acids, and base used and their volume-molecular concentrations were as follows:

Series A.—Dipotassium phosphate (K_2HPO_4), 0.0180 m.; sodium nitrate ($NaNO_3$), 0.0100 m.; calcium chlorid ($CaCl_2$). 0.0025 m.; magnesium sulphate ($MgSO_4$), 0.0025 m.; sodium hydroxid (NaOH), 0.0000 to 0.0100 m.; and citric acid ($H_3C_6H_5O_7$), 0.0100 to 0.0000 m.

Series B.—Potassium sulphate (K_2SO_4), 0.0040 m.; potassium nitrate (KNO_3), 0.0100 m.; $CaCl_2$, 0.0025 m.; $MgSO_4$, 0.0025 m., phosphoric acid (H_3PO_4), 0.0180 m., sodium hydroxid (NaOH), 0.0000 to 0.0360 m.

To each 500 cc. of culture solution there were added 5 drops of a ferric phosphate solution containing 0.25 gm. of $FePO_4$ per 100 cc.

VARIATION OF REACTION

The ideal method of adjusting the reaction in such a series of cultures

[1] Reference is made by number (italic) to "Literature cited," p. 93–95.

would be one which would permit a variation in unit steps over the desired range and at the same time produce solutions of sufficient stability to prevent small changes in the total amount of acid or base from seriously affecting the reaction. In other words, the solution should have a "buffer" nature. In the titration of strong acids with strong bases, a point is reached, as neutrality is approached, at which further additions of small increments of base produce very rapid decreases in the hydrogen-ion concentration. This corresponds to a rapid rise in the voltage curve obtained in the electrometric titration of such solutions. Any solution selected within this region of rapid change is unsuited to work requiring constancy of reaction, particularly when subject to possible small changes in total acidity. With acids and bases of low dissociation this difficulty is not so marked, changes of reaction being much less abrupt under similar conditions.[1] Such solutions are commonly said to possess a buffer nature and are well adapted to work similar to that herein reported.

In series A the reaction was varied by adding H_3C_6 and NaOH to the successive cultures in amounts equivalent to the following volume-molecular concentrations:

Culture No.	$H_3C_6H_5O_7$.	NaOH.
	M.	*M.*
1	0.0100	0.0000
2	.0080	.0020
3	.0060	.0040
4	.0040	.0060
5	.0030	.0070
6	.0020	.0080
7	.0000	.0100

The reaction curve as determined by the hydrogen electrode for this series is shown in figure 1, A.[2] It will be noted that this solution possesses sufficient buffer action to prevent any rapid changes in reaction with change in total content of acid and base.

[1] For a more complete discussion of this subject see Hillebrand (10).

[2] The measurements of hydrogen-ion concentration were made by means of the gas chain and hydrogen electrode, using the potentiometer system and measuring electromotive force to 0.0001 volt. For electrometric titrations a special cell equipped with mechanical stirring device was designed.

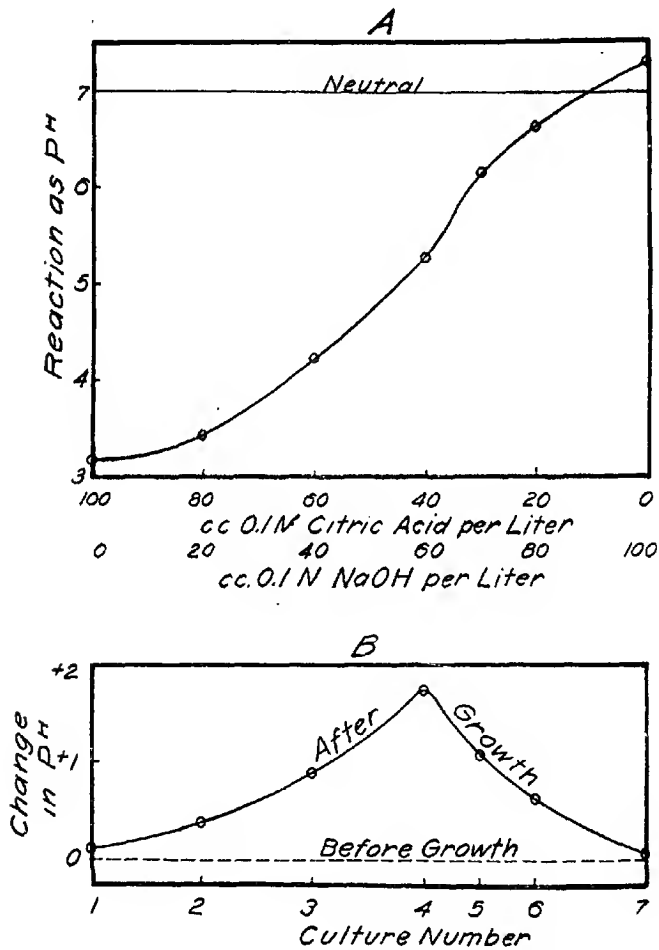

FIG. 1.—A, graph showing the relation of reaction to the contents of $HC_4H_5O_7$ and NaOH employed in the cultures of series A; B, graph showing the change of reaction found after 4 days' growth of wheat seedlings in series A.

In series B the reaction was varied by adding to all cultures sufficient H_3PO_4 to make the solution 0.0180 molecular and then NaOH in the following volume-molecular concentrations:

Culture No.	NaOH.
	M.
1	0.0000
2	.0144
3	.0174
4	.0181
5	.0198
6	.0288
7	.0360

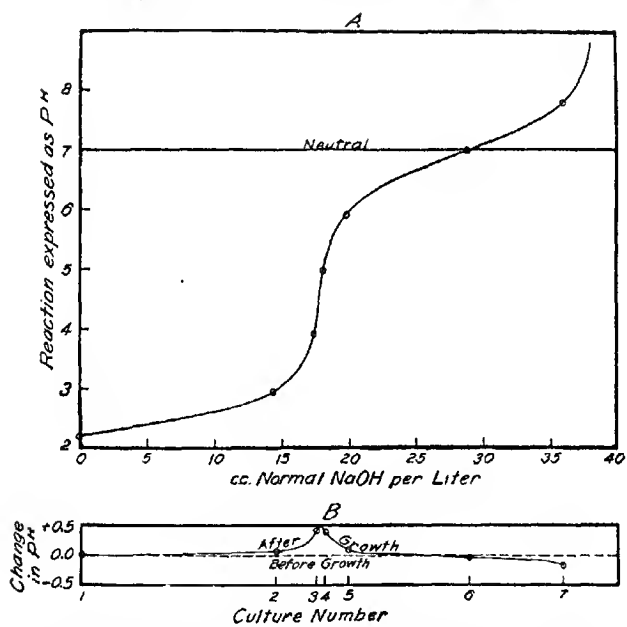

FIG. 2.—A, graph showing the change in reaction obtained by electrometric titration in series B; B, graph showing the change of reaction found after 4 days' growth of wheat seedlings in cultures of series B.

The electrometric titration curve for this solution (fig. 2, A) was used as a basis for determining the amounts of NaOH necessary to produce a series of seven cultures ranging from about 2 P_H to about 8 P_H and increasing in approximately equal steps of 1 P_H. The curve shows a rather abrupt rise at a point representing the complete neutralization of one hydrogen ion of the H_3PO_4 molecule. As will be shown later, the solutions chosen upon the steep part of the curve were less stable in reaction than those chosen upon the more nearly horizontal parts of the curve.

OSMOTIC CONCENTRATION

The osmotic concentrations of the solutions were not determined, because the data on the electrolytic dissociation of the component acids and salts under the variety of reactions used is not available and the authors did not have access to the necessary apparatus for making cryoscopic determininations. However, the relatively small change in total volume-molecular concentration within either series would indicate that little, if any, difference in growth within a given series should probably be attributed to the osmotic factor.

WATER EMPLOYED

All cultures were made from distilled water which had been rendered nontoxic by treating with carbon black as first recommended by Livingston (*14*).

TECHNIC OF GERMINATION AND GROWTH OF SEEDLINGS

The seeds of wheat, soybeans, and corn were germinated by supporting them upon a paraffined wire gauze which was floated by means of corks so that it was just even with the surface of nontoxic distilled water contained in a porcelain enameled pan. The seedlings were transferred to the various cultures when the plumules had attained a length of from 4 to 5 cm. The alfalfa seeds were germinated upon pads of filter paper in Petri dishes and transferred to the cultures after the seedling had attained a length of about 4 cm.

The wheat and alfalfa seedlings were grown in Non-Sol and Pyrex beakers holding 250 cc. of culture solution and were supported upon perforated caps of paraffined cheesecloth according to the method of Haas (*7*). The corn and soybean seedlings were grown in 8-ounce jars of flint glass and supported with corks according to the method of Tottingham (*26*). All beakers and jars were covered with black paper to exclude light. The solutions were renewed on all cultures every fourth day, and the glassware was thoroughly cleansed and sterilized before being used again. The reactions of the solutions used for growing wheat seedlings in both series were determined both before and after the 4-day periods. It was found that the successive solutions made up for a given reaction varied from each other by negligible amounts, so the solutions used for the growth of soybean, corn, and alfalfa seedlings were tested only at irregular intervals.

EXPERIMENTAL DATA AND DISCUSSION OF RESULTS

SERIES A

Wheat seedlings were grown for a period of 16 days in solutions having the composition given for series A. Growth was determined by taking the green weight of roots and tops, exclusive of seeds. Twelve seedlings were grown in each culture, and all seven cultures of the series were duplicated. The duplicate cultures agreed closely in all cases and are there-

fore not reported separately. The green weights obtained for tops, roots, and entire plants, exclusive of seeds, are given in Table II. The average reaction of each culture at the beginning and at the end of the 4-day periods and for the entire 16 days is also included in the table. The relative total green weights, based upon the highest, taken as 100, are shown in figure 3 plotted against the average P_H of the solutions, and the appearance of the seedlings at time of harvesting is shown in Plate 15, A, B.

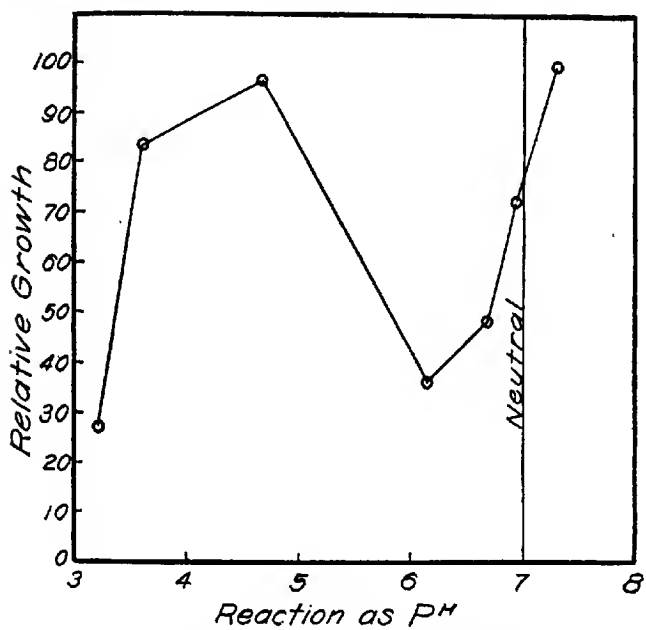

FIG. 3.—Graph showing the relation of growth of wheat seedlings to reaction in series A.

TABLE II.—*Average reaction of cultures in series A and green weights of plants grown for period of 16 days*

Culture No.	Average reaction of culture.			Green weight of 10 plants.		
	Before growth.	After growth.	Entire period.	Tops.	Roots.	Entire seedling.
	P_H.	P_H.	P_H.	*Gm.*	*Gm.*	*Gm.*
1	3.18	3.29	3.23	0.410	0.049	0.459
2	3.44	3.80	3.62	1.345	.079	1.425
3	4.22	5.10	4.67	1.440	.204	1.644
4	5.26	7.02	6.14	.570	.049	.619
5	6.15	7.21	6.68	.737	.091	.828
6	6.61	7.24	6.92	1.087	.171	1.258
7	7.28	7.34	7.31	1.375	.331	1.706

A brief consideration of the results obtained in this series shows them to be abnormal, since one would scarcely expect the decided drop in growth in cultures 4, 5, and 6 if reaction were the only factor concerned. The fact that there developed a decided opalescent or colloidal appearance in these cultures in about 24 hours after their renewal, together with the fact that there was a large decrease in acidity during the 4 days' growth of seedlings indicated that they were infected with some bacterial organism which evidently used the citric acid present as a source of energy. Microscopic examination of these solutions showed this to be the case, and it was at once surmised that the depressant effect of these solutions upon the growth of wheat seedlings was probably due to the assimilation of the nitrates by these bacteria. This hypothesis was substantiated by a determination of nitrates in all seven cultures at the end of a 4-day period. The relative total green weights of seedlings, based upon the highest taken as 100, the relative nitrate content, based upon the highest taken as 100, and the relative decrease in acidity of the solutions, based upon the greatest decrease taken as 100, are shown in Table III. The relation of the change in reaction taking place in the 4-day period to the original reaction of the solution is shown graphically in figure 1,B.

TABLE III.—*Comparative total green weights, nitrate content, and acidity of cultures of series A at end of 4-day period*

Solution No.	Relative yield (green weights of whole plants).	Relative amount of nitrates at end of 4-day period.	Relative decrease in acidity (increase in P_H).
	Gm.	*Gm.*	
1	26.9	84.0	6.2
2	83.5	92.8	22.2
3	96.4	78.0	50.0
4	36.3	6.0	100.00
5	48.5	7.8	60.3
6	73.7	24.0	35.8
7	100.0	100.0	3.4

The data show that depression in growth in cultures 4, 5, and 6 is associated with low amounts of nitrates left in solution and with large decrease in acidity. It seems safe, therefore, to conclude that the bacteria present were responsible for the abnormal effects obtained in this series. It should be noted that although there was more citric acid available to the bacteria in culture No. 3 than in No. 4, there was actually much smaller assimilation of nitrates in the former culture, while the wheat growth in No. 3 was almost equal to that in the best member of the series. Apparently the acidity of this culture has suppressed the growth of the nitrate-assimilating bacteria but has not had a correspondingly unfavorable effect on the growth of wheat seedlings. Since there was little difference in the amounts of nitrates present in cultures 1, 2, and 3 it seems

probable that the depression in growth found in cultures 1 and 2 was due to the physiological effect of their reaction upon the wheat seedlings.

The results obtained from this series do not give accurate data concerning the effect of reaction upon the growth of wheat seedlings over the entire range investigated. It seemed well, however, to include them in this report on account of their bearing upon a large amount of investigative work showing the ability of bacteria and fungi to compete with higher plants for inorganic nitrogen if supplied with a proper source of energy and carbon in the form of organic matter. This power of microorganisms has been demonstrated by numerous investigators under both solution and soil-culture methods. For a more complete discussion and an extensive bibliography on this subject the reader is referred to the publication of Doryland (*4*).

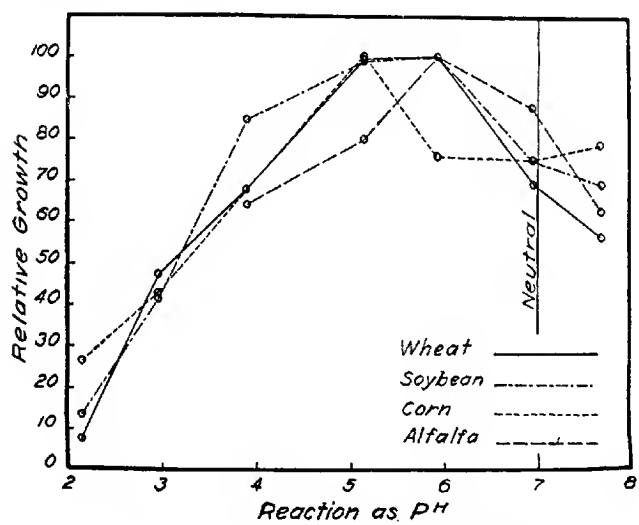

FIG. 4.—Graphs showing the relation of growth of wheat, soybean, corn, and alfalfa seedlings to reaction in series B.

SERIES B

On account of the difficulties arising from bacterial infection when citric acid was employed in the cultures, further work was confined to solutions having the composition given for series B. Wheat, soybeans, corn, and alfalfa seedlings were grown, all cultures being duplicated in the wheat, corn, and alfalfa series and quadruplicated in the soybean series. The numbers of seedlings grown in each culture were as follows: wheat, 12; soybean, 6; corn, 4; alfalfa, 20. The following periods of

growth were maintained: wheat, 18 days; soybeans, 16 days; corn, 8 days; alfalfa, 20 days. In Table IV are given the green weights of seedlings at time of harvesting and the average reaction of each culture as shown by the determinations of hydrogen-ion concentration made at the beginning and end of the 4-day periods on the cultures of the wheat series only. In figure 4 the relative total green weights, based upon the highest weight taken as 100 in each instance, are shown plotted against the average P_H of the cultures. Plate 15, C, shows the appearance of the wheat plants at the time of harvesting.

TABLE IV.—*Average reactions of cultures of series B and green weights of seedlings at time of harvesting*

WHEAT

Culture No.	Reaction.	Green weight of 10 plants.		
		Tops.	Roots.	Entire plants exclusive of seeds.
	P_H.	*Gm.*	*Gm.*	*Gm.*
1	2. 17	[a] 0. 230	[a] 0. 007	[a] 0. 297
2	2. 96	1. 730	. 143	1. 873
3	4. 11	2. 548	. 149	2. 697
4	5. 16	3. 581	. 372	3. 953
5	5. 94	3. 620	. 356	3. 976
6	6. 97	2. 421	. 324	2. 745
7	7. 71	2. 103	. 141	2. 244

SOYBEANS

Culture No.	Reaction. [b]	Green weight of 10 plants (entire).
	P_H.	*Gm.*
1	2. 17	[a] 4. 93
2	2. 96	7. 62
3	4. 11	15. 76
4	5. 16	18. 54
5	5. 94	18. 74
6	6. 97	14. 13
7	7. 71	12. 87

[a] Seedlings dead at time of harvesting.

[b] Because of the uniformity of reaction of successive cultures made up to to represent a given reaction and the relatively small changes in reaction produced by growth of seedlings it is assumed that the average reactions found in the wheat series apply to the cultures of the soybean, corn, and alfalfa series. Occasional determinations on cultures of the latter series showed this to be true.

TABLE IV.—*Average reactions of cultures of series B and green weights of seedlings at time of harvesting*—Continued

CORN

Culture No.	Reaction.[a]	Green weight of 10 plants, exclusive of seeds.
	P_H.	*Gm.*
1	2. 17	[b] 3. 53
2	2. 96	5. 66
3	4. 11	8. 98
4	5. 16	13. 30
5	5. 94	10. 14
6	6. 97	10. 03
7	7. 71	10. 47

ALFALFA

Culture No.	Reaction.[a]	Green weight of 10 plants (entire).
	P_H.	*Gm.*
1	2. 17	(b)
2	2. 96	(b)
3	4. 11	0. 317
4	5. 16	. 397
5	5. 94	. 496
6	6. 97	. 435
7	7. 71	. 310

[a] Because of the uniformity of reaction of successive cultures made up to represent a given reaction and the relatively small changes in reaction produced by growth of seedlings, it is assumed that the average reactions found in the wheat series apply to the cultures of the soybean, corn, and alfalfa series. Occasional determinations on cultures of the latter series showed this to be true.

[b] Seedlings dead at time of harvesting.

Before discussing the foregoing data mention should be made of the fact that while in practically all cases duplicate cultures agreed closely, there was occasionally considerable variation between the individual plants in a single culture of soybeans and corn, while in alfalfa there was considerable mortality among the plants in all cultures of the series. For this reason in drawing conclusions from the foregoing data the authors prefer to consider the work with soybeans, corn, and alfalfa as somewhat preliminary in nature. This does not apply to the wheat series, where no significant variations were found between the plants in the cultures representing a given reaction.

The effects of acids and alkalies upon seedings grown in solution culture have been quite extensively investigated by Kahlenberg and True (*13*), Heald (*9*), Cameron and Breazeale (*2*), Hartwell and Pember (*8*), Breazeale and LeClerc (*1*), Dachnowski (*3*), Miyake (*18*), Gedroitz (*6*), Loew (*15*), and Hoagland (*11*). A complete review of the reports

covering the work of these investigators is not deemed necessary in this paper, however, since with the exception of that of Hoagland, none of the foregoing researches are comparable with that herein reported, for the reason that actual measurements of hydrogen-ion or hydroxyl-ion concentrations were not made, total titratable acidity or basicity being taken as a measure of the reaction. This leads to erroneous conclusions where substances possessing a buffer nature, such as phosphates, are present in solution. On the other hand, results obtained from the use of solutions of single acids or bases are probably abnormal, since they lack the antagonistic effects noted in more complete nutrient cultures and probably operative under soil conditions. Furthermore, solutions of single strong acids or bases of the concentrations ordinarily employed in such work are extremely unstable and liable to large changes in reaction. This is particularly true in alkaline solutions where absorption of atmospheric carbon dioxid is not prevented. With organic acids there is also the possibility of change in reaction due to bacterial infection similar to that noted under series A of the present study.

Hoagland (*11*) investigated the effect of reaction on the growth of barley seedings grown in partial nutrient solutions of like osmotic concentration, in which the reaction was varied by the use of the various potassium phosphates. Reaction was determined by use of the hydrogen electrode. He found a hydrogen-ion concentration of 0.7×10^{-6} (5.15 P_H) to be favorable to growth, while a concentration of 0.3×10^{-3} (3.50 P_H) was very toxic. A concentration of hydroxyl ions greater than 1.8×10^{-6} (8.25 P_H) was found to be distinctly injurious, and when exceeding 2.5×10^{-5} (9.40 P_H) extremely toxic. It is unfortunate that no solution of reaction between 3.50 P_H and 5.15 P_H was employed in this work, since the former reaction was extremely toxic and the latter favorable to growth. This is particularly true, since it has been shown in the author's laboratory that this range of reaction represents a variation from a small to an unusually high total acidity (lime requirement) in soils.

In series B of the present study, a reaction of 5.94 P_H gave maximum growth of wheat and soybeans, and in both cases a reaction of 5.16 P_H was but slightly less favorable. With corn seedlings maximum growth occurred at a reaction of 5.16 P_H, while a reaction of 5.94 P_H was considerably less favorable. Maximum growth of alfalfa occured in the culture having a reaction of 5.94 P_H, while a reaction of 5.16 P_H considerably depressed the growth. A reaction of 4.11 P_H was somewhat less favorable to soybeans and distinctly less so to corn, wheat, and alfalfa than a reaction of 5.16 P_H. A reaction of 2.96 P_H resulted in the death of all alfalfa plants in the culture, and while there was some growth of wheat, soybeans, and corn, at the time of harvesting the leaves of all plants had begun to die at the tips. The roots of these plants produced no lateral growth at this reaction and at time of harvesting had turned

brown in color and supported vigorous growths of mold. It seems probable, therefore, that all plants would have died in these cultures and that 2.96 P_H is really below the critical reaction for all crops studied. A reaction of 2.17 P_H killed all seedlings a few days after transplanting, and while in Table IV weights are included for the seedlings from cultures having this reaction, these represent the weights of the dead seedlings at time of harvesting. Abundant growth of molds occurred upon the roots of all plants in cultures of this reaction. A reaction of approximate neutrality, 6.97 P_H, was found less favorable to the growth of seedlings of all four crops than a slightly acid reaction, while a reaction of 7.71 P_H still further depressed the growth of all crops excepting corn, where a slight increase was observed, the latter probably falling within experimental error. A study of the growth curves (fig. 4), shows that the optimum reaction for alfalfa was apparently higher than for the other crops studied. While maximum growth occurred at 5.94 P_H, a reaction of 6.97 P_H had a less injurious effect and a reaction of 5.16 P_H a more injurious effect than was found with wheat, soybeans, and corn. This agrees with the relative adaptation to soil reaction of the several crops commonly observed in field practice. In this connection it is interesting to note that Fred and Davenport (5) have recently shown that the critical reaction for the bacterium *Rhizobium leguminosarum*, symbiotically associated with alfalfa, is 4.9 P_H, while that for the corresponding organism associated with the soybean is 3.3 P_H.

CHANGE OF REACTION INCIDENT TO GROWTH

As previously noted, determinations of reaction by means of the hydrogen electrode were made upon the cultures of the wheat series at the beginning and end of each 4-day period—that is, before and after renewing the solution on each culture. The average reaction at the beginning and at the end of the 4-day periods for wheat in series B and the changes observed in reaction are given in Table V. The relation between the change of reaction and the position of a given culture with respect to the electrometric titration curve is brought out by a comparison of the curves shown in figure 2, A, and figure 2, B.

TABLE V.—*Change in reaction during 4-day periods*

Culture No.	Reaction before growth.	Reaction after growth.	Change in reaction.
	P_H.	P_H.	P_H.
1	2.17	2.17	0.00
2	2.94	2.98	+.04
3	3.90	4.31	+.41
4	4.95	5.36	+.41
5	5.90	5.98	+.08
6	6.99	6.95	−.04
7	7.79	7.62	−.17

It will be noted that the actual numerical value of the change in reaction is closely related to the stability of a given culture as indicated by the slope of the electrometric titration curve at the point representing the composition of the solution. There appears, however, to be a general tendency for the more acid cultures of the series to become slightly less acid while the more alkaline members tend to become slightly less alkaline. The conditions were not such as to permit accurate determination of the change in total titrable acidity or basicity produced by growth. However, if the points on the electrometric titration curve (fig. 2, A), corresponding to the reaction of each culture before and after growth of seedlings, are projected upon the horizontal axis representing quantity of total alkali added, it is found that in cultures 2 to 7, inclusive, there were no large differences in the quantitative value of the change in reaction—that is, a change in reaction of 0.41 P_H in culture 3 or 4 does not necessarily correspond to a greater change in total acidity than a change of 0.08 P_H in culture 5. The exact cause of the change in reaction, whether due to root excretions, to selective ionic absorption, or to other factors, was not determined. The results obtained agree with those of Pantanelli (*20*), who found a general tendency for plants grown in solution culture to regulate the reaction towards that most favorable to growth. The results agree also with the more recent work of Hoagland (*11*, *12*), who found that barley grown in partial and complete nutrient cultures caused the reaction to approach that of approximate neutrality. On account of the difference in conditions the foregoing data are not necessarily contradictory to the results of Breazeale and LeClerc (*1*), who grew wheat seedlings in solutions of the single salts K_2SO_4, potassium chlorid (KCl), and $NaNO_3$ and found a development of acidity in the potassium salts and of basicity in $NaNO_3$ apparently due to selective ionic absorption. However, in the more recent work of Hoagland (*12*), who grew barley plants in single salt solutions of KCl, K_2SO_4, $MgSO_4$, potassium phosphate (K_3PO_4), ammonium chlorid (NH_4Cl), and $NaNO_3$, he found that—

> in no case was a condition either of excessive OH ion or H ion concentration produced, although absorption had been active. The acid reaction when present was due to slightly dissociated acids, usually carbonic, or to acid salts in the case of NH_4Cl solution. Possibly in some cases organic acids were formed.

In this connection it should be mentioned that Haas (*7*) grew wheat seedlings in distilled water and found no change of reaction, measurements being made after carbon dioxid had been removed.

POSSIBLE INFLUENCE OF FACTORS OTHER THAN REACTION

While it seems probable that the variations observed in the growth of the seedlings under the range of reactions employed were the direct

result of the variation in reaction, yet it should be noted that certain other factors might have been operative to an undetermined extent.

Attention has already been called to the probable small variations in osmotic concentrations of the cultures within a given series. It seems doubtful whether such variations could have exerted any appreciable effect.

There was a variation in sodium content from an equivalent concentration of zero in culture 1 to 0.0360 in culture 7 of series B. It has recently been shown in the researches of Shive (*25*) that the substitution of an equivalent amount of sodium phosphate (NaH_2PO_4) for part of the potassium phosphate (KH_2PO_4) of a 3-salt nutrient culture produced considerable increases in the growth of soybean seedlings. In the present work, however, the greatest variations in growth were associated with the smallest changes in sodium content. Thus culture 2, to which had been added sodium as NaOH equivalent to 0.0144 m. was apparently below the critical reaction for all plants studied, while maximum growth of all plants was obtained in either culture No. 4 or No. 5 to which had been added NaOH equivalent to 0.0181 m. and 0.0198 m., respectively. It seems highly improbable that the variations in growth could have been to any appreciable extent induced by such small variations in the total sodium content.

The contents of calcium and magnesium employed in the cultural solutions were purposely kept low. (See Table I.) There was nevertheless a trace of precipitate of the phosphates of these metals formed in culture 6, which had a reaction of 6.97 P_H, and a somewhat more abundant precipitate in culture 7, which had a reaction of 7.71 P_H. To what extent the change in concentration thus produced might have influenced the results was not determined. Attention has previously been called to the possibility of similar changes in solubility of these elements at corresponding reactions under soil conditions.

In the work of Shive (*25*), previously mentioned, a toxicity of monobasic phosphates was shown toward soybeans grown in soil and in solution culture. While a general relation between the degree of injury sustained by the plants and the total acidity of the cultures was noted in this work, the fact that determinations of hydrogen-ion concentration were not made prevented accurate conclusions as to the actual part played by the acidity factor in the production of the injurious effects associated with the monophosphate group. The data obtained in the present study indicate that there was probably little effect of the H_2PO_4 group aside from that produced by the hydrogen ion formed in its dissociation. This is brought out by the fact that in culture 4 there was maximum growth of corn seedlings and very nearly maximum growth of wheat and soybean seedlings; whereas in the composition of this solution, H_3PO_4 equivalent to a concentration of 0.0180 m. and NaOH equivalent to a concentration of 0.0181 m. were employed—that is,

approximately enough alkali was used just to neutralize the first hydrogen ion of the H_3PO_4 molecule. The concentration of the monophosphate group was undoubtedly higher in this culture, therefore, than in any others of the series, since all the phosphorus present existed as the equivalent of monosodium phosphate. In the cultures below No. 4 an increasing part of the phosphorus exists as H_3PO_4, while in the cultures above No. 4 an increasing amount exists as sodium phosphate (Na_2HPO_4).

THE EFFECT OF REACTION ON GERMINATION

The effects of acids and alkalies upon the germination of seeds have been studied by Promsy (*22, 23*), Micheels (*16, 17*), and Plate (*21*). The general conclusions can be drawn from these investigations that a slightly acid reaction is favorable to the germination of most seeds, while bases exert an injurious effect. The relation of germination to acidity varies considerably with seeds of different plants and with the acid used, organic acids being apparently more favorable than inorganic when used in equivalent amounts. This is probably due to their lower dissociation. Promsy found that the optimum concentration of acids ranged from 0.5 to 5 parts per thousand, depending upon the nature of the seed and the acid employed. Higher concentrations of acid inhibit or prevent germination. It is asserted that the effects of acids and bases on germination are a result of their favorable or unfavorable influence on the enzymic processes concerned.

The authors are not familiar with any work showing the effect of reaction on germination in which hydrogen-ion or hydroxyl-ion concentration is taken as a measure of the reaction, or with any work showing the relative sensitivity of germination and of the subsequent growth of the plant to reaction so determined. Breazeale and LeClerc (*1*), in explaining some of their results obtained in the growth of wheat seedlings in acid cultures, draw the conclusion that the depressant effect of acidity is greater during germination than in the subsequent growth of the plant. They explain this by assuming a high sensitivity of the enzyms concerned in germination, particularly the oxidases and peroxidases, to the acid condition. From a practical standpoint it would seem desirable to know to what extent the effects of soil acidity are due to its injurious influence on germination and to its effects on the subsequent growth of the crop. Numerous instances have come under the authors' observation in which seed planted in soils of high acidity apparently germinated normally but either ceased to grow or died after the plants had attained a small growth. This would indicate a condition opposite to the conclusion of Breazeale and LeClerc (*1*).

To investigate this point seeds of wheat, corn, soybeans, alfalfa, and red clover were germinated in solutions having the same nutrient composition and reaction as those used in the growth of seedlings in series B. The seeds were germinated upon pads of three ashless filters placed in Petri

dishes in which had been placed porcelain plates of such size as to prevent submersion of the filter paper in the solution except at the periphery of the dish. At the beginning of the experiment 20 cc. of the proper solution were added to each dish, allowed to stand 10 minutes, poured off, and replaced with 20 cc. of fresh solution. This was done in order to guard against change in concentration due to adsorption of solutes by the filter paper. The number of seeds germinated in each dish was as follows: alfalfa, 40; red clover, 50; corn, 10; soybeans, 10; wheat, 25. To avoid the effect of individual variation the dishes were triplicated in the test with corn and duplicated in the test with soybeans. The solution was renewed on all dishes every other day. The dishes were kept at room temperature for seven days, at which time a germination count

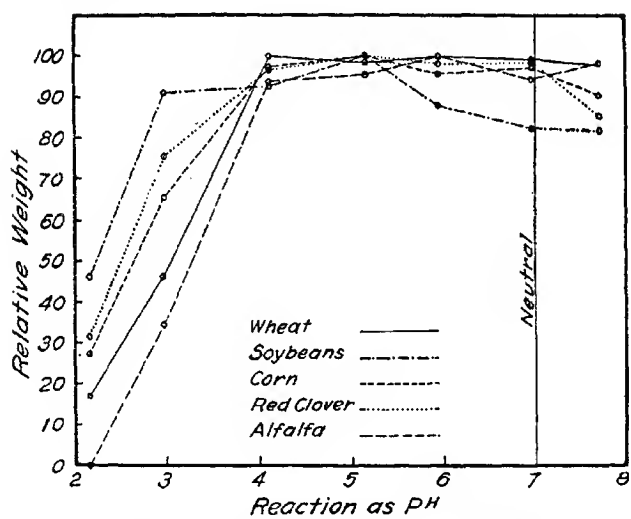

FIG. 5.—Graphs showing the relative weights of sprouts produced by seeds of wheat, corn, soybeans, alfalfa, and red clover in 7-day germination period at various reactions.

was taken and the green weight of the sprouts determined. The weight was taken for the entire seedling of the legumes, but the seeds were excluded in weighing the wheat and corn.

The number of seeds germinating in each culture and the average weights of the sprouts from 10 seeds are given in Table VI. The relative green weights of sprouts, based upon the largest weight taken as 100 in each instance, are shown plotted against the reaction of the cultures in figure 5.

TABLE VI.—*Number of seeds germinating and average green weight of sprouts from 10 seeds*

ALFALFA, 40 SEEDS TESTED

Dish No.	Reaction.	Number of seeds germinating.	Average weight of sprouts.	Notes.
	P_H.		*Gm.*	
1	2.17	0	.....	Much mold, seeds swelled but no sprouts.
2	2.96	30	0.066	Some mold.
3	4.11	35	.181	No mold.
4	5.16	33	.184	Do.
5	5.94	33	.193	Do.
6	6.97	35	.182	Do.
7	7.71	27	.190	Do.

RED CLOVER, 50 SEEDS TESTED

1	2.17	5	0.048	Much mold, sprouts dead.
2	2.96	43	.115	Root tips brown and dead, some mold.
3	4.11	50	.148	No mold.
4	5.16	47	.153	Do.
5	5.94	45	.150	Do.
6	6.97	45	.151	Do.
7	7.71	47	.131	Do.

SOYBEANS, 20 SEEDS TESTED

1	2.17	4	1.665	Much mold, sprouts dead.
2	2.96	20	3.284	Root tips brown and dead, some mold.
3	4.11	18	3.350	No mold.
4	5.16	20	3.607	Do.
5	5.94	20	3.173	Do.
6	6.97	19	2.975	Do.
7	7.71	20	2.960	Do.

TABLE VI.—*Number of seeds germinating and average green weight of sprouts from 10 seeds*—Continued

CORN, 30 SEEDS TESTED

Dish No.	Reaction.	Number seeds germinating.	Average green weight of sprouts.	Notes.
	P_H.		*Gm.*	
1	2.17	26	0.941	Small growth of mold, sprouts dead.
2	2.96	29	2.247	No mold.
3	4.11	29	3.357	Do.
4	5.16	30	3.447	Do.
5	5.94	30	3.293	Do.
6	6.97	29	3.353	Do.
7	7.71	29	3.130	Do.

WHEAT, 25 SEEDS TESTED

1	2.17	16	0.198	Much mold, sprouts dead.
2	2.96	22	.541	Some mold.
3	4.11	25	1.163	No mold.
4	5.16	22	1.143	Do.
5	5.94	23	1.164	Do.
6	6.97	25	1.156	Do.
7	7.71	23	1.141	Do.

While there is evidence of some abnormalities in the foregoing data, the authors believe the following conclusions are justified:

A reaction of 4.11 P_H did not exert a depressing effect on the germination of any of the seeds studied as measured by the germination count and the green weight of the sprouts at the end of the 7-day period. It will be recalled that the same reaction was found to depress the growth of seedlings of alfalfa, soybeans, corn, and wheat. Apparently the process of germination is not so susceptible to injury by acidity as is the subsequent process of growth with these plants.

A reaction of 2.96 P_H did not have any considerable effect upon the number of seeds germinating but considerably reduced the weight of the sprouts produced except with soybeans. In the latter case the roots had begun to turn brown in color and die at the tips at the end of the 7-day period. Some mold grew on the seeds in all dishes of this reaction.

Swelling of all seeds took place in dishes having a reaction of 2.17 P_H, and some small sprouts were produced from all seeds except those of alfalfa. All sprouts were apparently dead at the end of the 7-day period, and a severe growth of mold was present in all dishes of this reaction.

A reaction of 7.71 P_H decreased to a slight extent the weight of sprouts of all plants except alfalfa and wheat but did not appreciably lower the number of seeds germinating.

The optimum reaction for the germination of the seeds of the five plants studied is probably below 7.71 P_H and above 2.96 P_H.

GENERAL APPLICATION OF RESULTS TO FIELD PRACTICE

Most experiment stations recommend the use of such amounts of lime as will neutralize the total acidity present and maintain a soil at a neutral or slightly alkaline reaction. The results herein reported would indicate that if the direct physiological effect of excessive acidity upon plant growth were the only factor concerned, it would be more desirable to recommend such amounts of lime as would maintain the soil at a slightly acid reaction such as would be represented by a P_H value of 5 or 6. On the other hand, attention has been called to the necessity of further investigation of the other factors associated with acidity before this conclusion is warranted. Thus, a high optimum reaction (in P_H) for the development of the nitrogen-transforming organisms of a soil might counterbalance completely the advantages of a slightly acid reaction for the growth of the plant itself. The authors have investigations in progress, including solution, pot, and field plot studies, which it is hoped will give further evidence upon the part played by the other factors concerned.

SUMMARY

(1) A study has been made of the effects of reaction, as measured by hydrogen-ion concentration, upon the growth of the seedling of wheat, soybeans, corn, and alfalfa in solution culture and upon the germination of the seeds of wheat, soybeans, corn, alfalfa, and red clover, under conditions permitting the elimination or control of factors other than reaction.

(2) Citric acid was found unsuitable for adjusting the reaction of culture solutions for such work on account of bacterial infection which produced rapid changes in reaction and nitrate content. The nitrate-assimilating bacteria in this case were found more sensitive to acidity than were wheat seedlings.

(3) A satisfactory method of adjusting the reaction of the culture solutions was found to be the addition of a uniform amount of H_3PO_4 to all cultures and increasing amounts of NaOH to successive cultures.

(4) Maximum growth of seedlings of wheat, soybeans, and alfalfa occurred in cultures having a reaction of 5.94 P_H, while corn produced greatest growth in the cultures having a reaction of 5.16 P_H.

(5) A reaction of 5.16 P_H was approximately equal to 5.94 P_H for the growth of soybeans and wheat but decidedly less favorable for the growth of alfalfa.

(6) A reaction of 4.11 P_H was somewhat less favorable to soybeans and distinctly less favorable to corn, wheat, and alfalfa than a reaction of 5.16 P_H.

(7) A reaction of 2.96 P_H is probably below the critical reaction for all plants studied.

(8) A reaction of 2.16 P_H caused the death of the seedlings of all plants within a comparatively short time and was found to favor the growth of molds in the cultures.

(9) A reaction of approximate neutrality (6.97 P_H) was slightly less favorable to alfalfa and decidedly less so to wheat, corn, and soybeans than a slightly acid reaction.

(10) A reaction of 7.71 P_H produced further depression of growth beyond that observed at 6.97 P_H except in the case of corn seedlings.

(11) The hydroxyl ion was apparently more harmful than the hydrogen ion in equivalent concentrations.

(12) Measurements of reaction of solutions before and after the growth of wheat seedlings showed a general tendency for the plant to adjust the reaction toward a point slightly below neutrality.

(13) The actual value of the change of reaction produced by the growth of seedlings in a given culture was found to be a function of the stability of the solution as indicated by the slope of the electrometric titration curve at the point representing the composition of the solution.

(14) No indication was obtained of any harmful effect of the monophosphate group, H_2PO_4, other than that produced by the hydrogen ion formed through its dissociation.

(15) Germination of the seed was found less sensitive to an acid reaction in wheat, corn, soybeans, and alfalfa than was the subsequent growth of the seedling.

(16) A reaction of 4.11 P_H did not exert a depressing effect on the germination of any of the seeds studied.

(17) A reaction of 2.96 P_H did not appreciably affect the number of seeds germinating but considerably reduced the weight and apparent vigor of the sprouts produced.

(18) A reaction of 2.16 P_H did not prevent the formation of sprouts except in alfalfa, but all sprouts produced were dead at the end of the 7-day germination period. This reaction induced the extensive growth of molds upon the seeds.

(19) The optimum reaction for the germination of the seeds of the five plants studied is probably below 7.71 P_H and above 2.96 P_H, a slightly acid reaction being found most favorable in all cases.

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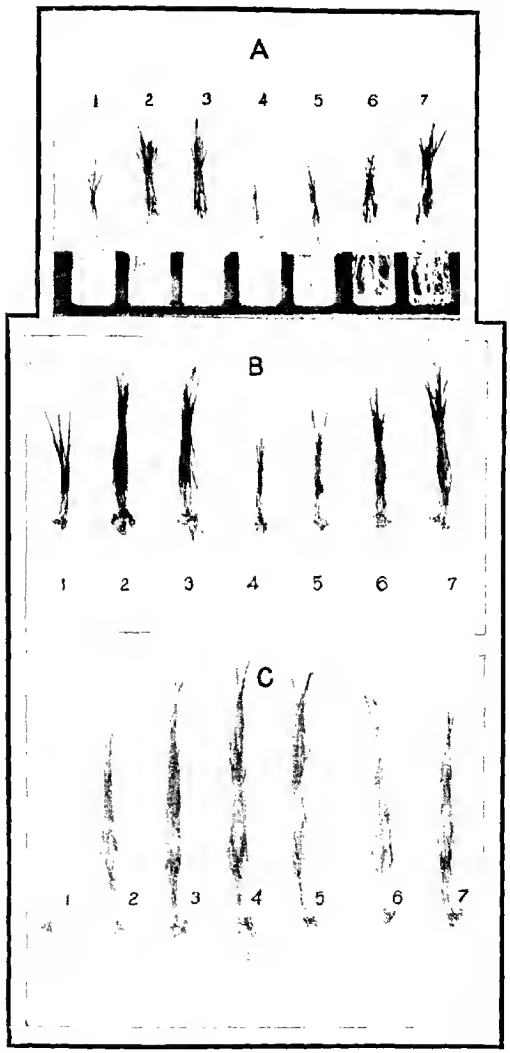
PLATE 15

A.—Method of growing wheat seedlings. (Paper covers removed from beakers.)
B.—Appearance of wheat seedlings in series A at time of harvesting.
C.—Appearance of wheat seedlings in series B at time of harvesting.


A
1 2 3 4 5 6 7
B
1 2 3 4 5 6 7
C
1 2 3 4 5 6 7